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Digital Mapping Techniques '09

Association of American State Geologists

United States Geological Survey

Digital Mapping Techniques '09—Workshop Proceedings

May 10–13, 2009
Morgantown, West Virginia

Convened by the
Association of American State Geologists
and the
United States Geological Survey
Hosted by the
West Virginia Geological Survey

U.S. Geological Survey Open-File Report 2010–1335

U.S. Department of the Interior
U.S. Geological Survey

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Edited by David R. Soller

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2011

U.S. Department of the Interior
U.S. Geological Survey

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Introduction

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The Digital Mapping Techniques '09 (DMT'09) workshop was attended by 90 technical experts from 42 agencies, universities, and private companies, including representatives from 24 State geological surveys (see Appendix A). This workshop, hosted by the West Virginia Geological and Economic Survey, May 10-13, 2009, on the West Virginia University campus in Morgantown, West Virginia, was similar in nature to the previous 12 meetings (see Appendix B). The meeting was coordinated by the National Geologic Map Database project. As in the previous meetings, the objective was to foster informal discussion and exchange of technical information. It is with great pleasure that I note that the objective was again successfully met, as attendees continued to share and exchange knowledge and information, and renew friendships and collegial work begun at past DMT workshops.

At this meeting, oral and poster presentations and special discussion sessions emphasized (1) methods for creating and publishing map products (here, "publishing" includes Web-based release); (2) field data capture software and techniques, including the use of LiDAR; (3) digital cartographic techniques; (4) migration of digital maps into ArcGIS Geodatabase format; (5) analytical GIS techniques; and (6) continued development of the National Geologic Map Database.

Acknowledgments

I thank the West Virginia Geological and Economic Survey (WVGES) and the Director and State Geologist, Michael Hohn, for hosting this meeting. I especially wish to thank Scott and Jane McColloch for coordinating all of the events. Scott and Jane have been a part of the DMT meeting series for many years, their contributions to its success are great, and it's always a pleasure to work with them. Many other members of the WVGES and West Virginia University provided important assistance that ensured the meeting's success, I am indebted to them. They are John M. Bocan, John D. May, Michael A. Kirk, Susan C. Kite, Robert and Abraham Johnson, Gary W. Daft, Evan J. Moser, James M. Horner, Paula J. Hunt, Sarah E. Gooding, Jennifer L. Stump, Susan E. Pool, Jeanne M. Sutton, Keri L. Wilson, Gloria J. Rowan, Katherine L. Avary, Mary C. Behling, Thomas E. Repine, and Judith A. Sparks (WVGES), and Gregory A. Elmes, Timothy A. Warner, J. Steven Kite, Randy D. Crowe, Eric J. Hopkins, Frank LaFone, Tracye J. Tennant, and Hope M. Stewart (WVU Department of Geology and Geography).

Last, but not least, I thank all attendees for their participation; their enthusiasm and expertise were the primary reasons for the meeting's success.

Presentations and Posters

The workshop included 17 oral presentations, 3 discussion sessions, and 23 posters. Many are supported by a paper contained in these Proceedings. The papers describe technical and procedural approaches that currently meet some or all needs for digital mapping at the respective agency. There is not, of course, a single "solution" or approach to digital mapping that will work for each agency or for each program or group within an agency; personnel and funding levels, and the schedule, data format, and manner in which we must deliver our information to the public require that each agency design its own approach. However, the value of this workshop and other forums like it is through their roles in helping to design or refine these agency-specific approaches to digital mapping and to find applicable approaches used by other agencies.

In other words, communication helps us to avoid having to "reinvent the wheel."

During the course of the 13 annual DMT meetings, it has been my pleasure to meet, and work with, the many talented people who have authored papers in these Proceedings. As the subjects addressed by the DMT meetings have become even more essential to the Nation's geological surveys, the demands placed on them have risen to the point where many authors scarcely have time to address their work fully. Predictably, less time is then available to compose written summaries of their work; I'm sure the readers (or at least other editors) can sympathize with this predicament. Therefore, I include with this Introduction a list of all presentations and posters (Appendix C). If the reader finds an interesting title that isn't recorded in these Proceedings, I encourage the reader to contact the authors directly. Further, some presentations and related information are available for download at *http://ngmdb.usgs.gov/Info/dmt/DMT09presentations.html*.

The Next DMT Workshop

The 14th annual DMT meeting will be held in the spring of 2010 in Sacramento, California. Please consult the Web site (*http://ngmdb.usgs.gov/Info/dmt/*) for additional information about this and other DMT meetings.

Appendix A. List of Workshop Attendees

[Grouped by affiliation]

American Association of Petroleum Geologists
Jingyao Gong

Alaska Division of Geological and Geophysical Surveys
Jennifer E. Athey

Arizona Geological Survey
Ryan Clark
Steven M. Richard

Auburn University
Bart Davis

British Geological Survey
Jeremy Giles
Colm J. Jordan

Canaan Valley Institute
Paul Kinder
Janette McNeer

Colorado Geological Survey
Dave Noe

Colorado State University (National Park Service Cooperator)
Ronald D. Karpilo
Stephanie A. O'Meara

Delaware Geological Survey
John A. Callahan
William S. Schenck

ESRI
Janel Day
Charlie Frye
Willy Lynch

Fugro-William Lettis & Associates, Inc.
Mark Zellman

Georgia DNR - Environmental Protection Division
John Costello

Geological Survey of Alabama
Philip Dinterman

Geological Survey of Canada
Parm Dhesi
Vic Dohar
Phil O'Regan

Government of Newfoundland and Labrador
Larry Nolan

Idaho Geological Survey
Jane Freed
Loudon Stanford

Illinois State Geological Survey
Don McKay

Kansas Geological Survey
Bill Harrison

Kentucky Geological Survey
Gerald A. Weisenfluh

Louisiana Geological Survey
Robert Paulsell

Maine Geological Survey
Bob Marvinney

Michigan Office of Geological Survey
John Esch

Missouri Division of Geology and Land Survey
Cheryl Seeger

National Park Service, Geologic Resources Division
Andrea Croskrey
Georgia Hybels

Ohio Geological Survey
Paul Hoeffler
James McDonald
Donovan Powers

Oregon State Department of Geology and Minerals Industries
Jed T. Roberts
Sarah Robinson
Mathew Tilman

Pennsylvania Geological Survey
Jaime Kostelnik
Victoria Neboga
Tom Whitfield

South Carolina Geological Survey
Scott Howard

Techna-Graphics, Inc.
David Mecklenburg

University of Tennessee, Knoxville
Andrew W. Wunderlich

The University of Alabama
Doug Behm

U.S. Geological Survey
Stafford Binder
Pete Chirico
Mary DiGiacomo-Cohen
Dan Doctor
Joe East
Tracey Felger
Christopher P. Garrity
Linda Gundersen
Rich Harrison
Ralph Haugerud
Linda Jacobsen
Peter Lyttle
Tim Miller
Craig Neidig
Randall Orndorff
Frances Pierce
David R. Soller
Nancy R. Stamm
Byron Stone
Dave Weary

Minnesota Geological Survey
Richard Lively

USDA Forest Service--Minerals and Geology Management
Courtney Cloyd

Utah Geological Survey
Kent Brown

Vincennes University
Adam M. Davis

Virginia Division of Geology and Mineral Resources
Amy Gilmer

West Virginia Geological and Economic Survey
John Bocan
Gary Daft
Sarah Gooding
Jamie Horner
Paula Hunt
Bob Johnson
Susan Kite
Jane McColloch
Scott McColloch, Jr.
Evan Moser
Susan Pool
Jenny Stump
Keri Wilson

West Virginia GIS Technical Center
Eric Hopkins

West Virginia University Department of Geology and Geography
Greg Elmes

Wisconsin Geological Survey
Kathy Roushar

Appendix B. Previous Digital Mapping Techniques workshops

1997:
Hosted by the Kansas Geological Survey, Lawrence, Kansas, June 2-5. 73 technical experts attended, from 30 State geological surveys, the USGS, and the Geological Survey of Canada.

Soller, D.R., ed., 1997, Proceedings of a workshop on digital mapping techniques: Methods for geologic map data capture, management, and publication: U.S. Geological Survey Open-File Report 97-269, 120 p., *http://pubs.usgs.gov/of/of97-269/*.

1998:
Hosted by the Illinois State Geological Survey in Champaign, Illinois, May 27-30. More than 80 technical experts attended, mostly from the State geological surveys and the USGS.

Soller, D.R., ed., 1998, Digital Mapping Techniques '98—Workshop Proceedings: U.S. Geological Survey Open-File Report 98-487, 134 p., *http://pubs.usgs.gov/of/of98-487*/.

1999:
Hosted by the Wisconsin Geological and Natural History Survey in Madison, Wisconsin, May 19-22. 91 selected technical experts from 42 agencies, universities, and private companies attended, including representatives from 30 State geological surveys.

Soller, D.R., ed., 1999, Digital Mapping Techniques '99—Workshop Proceedings: U.S. Geological Survey Open-File Report 99-386, 216 p., *http://pubs.usgs.gov/of/of99-386/front.html*.

2000:
Hosted by the Kentucky Geological Survey in Lexington, Kentucky, May 17-20. 99 technical experts from 42 agencies, universities, and private companies attended, including representatives from 28 State geological surveys.

Soller, D.R., ed., 2000, Digital Mapping Techniques '00—Workshop Proceedings: U.S. Geological Survey Open-File Report 00-325, 209 p., *http://pubs.usgs.gov/of/of00-325*/.

2001:
Hosted by the Geological Survey of Alabama, in Tuscaloosa, Alabama, May 20-23. 108 technical experts from 48 agencies, universities, and private companies attended, including representatives from 31 State geological surveys.

Soller, D.R., ed., 2001, Digital Mapping Techniques '01—Workshop Proceedings: U.S. Geological Survey Open-File Report 01-223, 248 p., *http://pubs.usgs.gov/of/2001/of01-223/*.

2002:
Hosted by the Utah Geological Survey, in Salt Lake City, Utah, May 19-22. More than 100 technical experts from 40 agencies, universities, and private companies attended, including representatives from 30 State geological surveys.

Soller, D.R., ed., 2002, Digital Mapping Techniques '02—Workshop Proceedings: U.S. Geological Survey Open-File Report 02-370, 214 p., *http://pubs.usgs.gov/of/2002/of02-370/*.

2003:
Hosted by the Pennsylvania Geological Survey, in Millersville, Pennsylvania, June 1-4. Nearly 90 technical experts from 36 agencies, universities, and private companies attended, including representatives from 22 State geological surveys.

Soller, D.R., ed., 2003, Digital Mapping Techniques '03—Workshop Proceedings: U.S. Geological Survey Open-File Report 03-471, 262 p., *http://pubs.usgs.gov/of/2003/of03-471/*.

2004:
Hosted by the Oregon Department of Geology and Mineral Industries, in Portland, Oregon, May 16-19. Nearly 100 technical experts from 40 agencies, universities, and private companies attended, including representatives from 22 State geological surveys.

Soller, D.R., ed., 2004, Digital Mapping Techniques '04—Workshop Proceedings: U.S. Geological Survey Open-File Report 2004-1451, 220 p., *http://pubs.usgs.gov/of/2004/1451/*.

2005:
Hosted by the Louisiana Geological Survey, in Baton Rouge, Louisiana, April 24-27. More than 100 technical experts from 47 agencies, universities, and private companies attended, including representatives from 25 State geological surveys.

Soller, D.R., ed., 2005, Digital Mapping Techniques '05—Workshop Proceedings: U.S. Geological Survey Open-File Report 2005-1428, 268 p., *http://pubs.usgs.gov/of/2005/1428*/.

2006:
Hosted by the Ohio Geological Survey, in Columbus, Ohio, June 11-14. More than 115 technical experts from 51 agencies, universities, and private companies attended, including representatives from 27 State geological surveys.

Soller, D.R., ed., 2007, Digital Mapping Techniques ‘06—Workshop Proceedings: U.S. Geological Survey Open-File Report 2007-1285, 217 p., *http://pubs.usgs.gov/of/2007/1285/*.

2007:
Hosted by the South Carolina Geological Survey, in Columbia, South Carolina, May 20-23. More than 85 technical experts from 49 agencies, universities, and private companies attended, including representatives from 27 State geological surveys.

Soller, D.R., ed., 2008, Digital Mapping Techniques ‘07—Workshop Proceedings: U.S. Geological Survey Open-File Report 2008-1385, 140 p., *http://pubs.usgs.gov/of/2008/1385/*.

2008:
Hosted by the Idaho Geological Survey, in Moscow, Idaho, May 18-21, 2008. More than 100 technical experts from 39 agencies, universities, and private companies attended, including representatives from 19 State geological surveys.

Soller, D.R., ed., 2009, Digital Mapping Techniques ‘08—Workshop Proceedings: U.S. Geological Survey Open-File Report 2009–1298, 217 p., *http://pubs.usgs.gov/of/2009/1298/*.

Appendix C. List of Oral and Poster Presentations, and Discussion Sessions

Oral Presentations

Overview of West Virginia's Geology
By Scott McColloch, Jr. (West Virginia Geological and Economic Survey)

Building a National Archive – Standards Development and the U.S. National Geologic Map Database
By David R. Soller and Nancy R. Stamm (U.S. Geological Survey)

A Practitioner's Guide to Managing Geoscience Information
By Jeremy Giles (British Geological Survey)

Building an Enterprise Geotechnical Database to Support Geologic Mapping Activities
By Gerald A. Weisenfluh (Kentucky Geological Survey)

Semi-automated mapping of surficial geologic deposits from digital elevation models (DEMs) and hydrologic network data
By Peter G. Chirico (U.S. Geological Survey)

ESRI Cartographic Representations for the FGDC Digital Cartographic Standard for Geologic Map Symbolization
By Charlie Frye and Janel Day (ESRI)

USGS Topographic Maps from The National Map
By Stafford Binder, Greg Allord, and Michael J. Cooley

A New Delaware DataMIL and Delaware DataMIL topographic maps that replace USGS topo maps for Delaware
By William S. Schenck (Delaware Geological Survey)

Lidar based DEM slope-shapes – seeing through the canopy
By Thomas G. Whitfield (Pennsylvania Geological Survey)

Discussion Session: "Acquiring high-quality digital base maps"
Geologic mapping projects now depend on digital base maps rather than the standard paper (or Mylar) base map of the past, and significantly more effort is now needed to acquire the base map. There are many sources for digital base maps, many methods of creating them, and their quality is uneven. Easy access to standardized, high-quality digital base map layers (perhaps including, but not limited to, LIDAR) is desirable; this session addressed the technical issues and attempted to provide guidance to management.

SIGMAmobile, the British Geological Survey digital field mapping system in action
By Colm J. Jordan (British Geological Survey)

A Desktop Analysis of Proposed Wind Farm Sites; Southeastern and Coastal California
By Mark Zellman, Chris Hitchcock, Ranon Dulberg, and David Slayter (William Lettis & Associates)

Using Google tools to aid geologic mapping in a low-relief karst terrain, northern Virginia
By Daniel Doctor (U.S. Geological Survey) and Katarina Doctor (George Mason University)

Credit where credit's due: developing authorship strategies at the Journal of Maps
By Mike J. Smith (Kingston University, U.K.), and Colm J. Jordan and Jenny C. Walsby (British Geological Survey)

Improving ArcGIS workflow through automation using VBA
By Andrew L. Wunderlich (University of Tennessee, Knoxville)

Mapping Exercises for Freshmen and Sophomore College Students
By Adam M. Davis (Vincennes University)

Web Map Services and Catalog Services in the U.S. Geoscience Information Network
By Stephen M. Richard (Arizona Geological Survey / U.S. Geological Survey)

Why doesn't your model pass information to mine?
By Jeremy Giles and Holger Kessler (British Geological Survey)

Discussion Session: "NCGMP09 – a proposed standard format for publication of geologic maps"
This database design addresses the critical need to produce simple yet useful GIS products for individual geologic maps. The design was released at this meeting, with request for evaluation and refinement. This session was one outcome of the DMT'08 Discussion Session "Can we develop national standards and guidelines for geologic map databases?"

Discussion Session: "Cartographic Design and Map Production"
An informal time to show maps and to discuss map design and preparation techniques. This session included a GSA-style "Map Blast" (an informal display of posters) and a group discussion.

Poster Presentations (listed alphabetically, by author):

Shepherding geologic data from the outcrop to publication (and beyond?)
By Jennifer E. Athey and DGGS staff (Alaska Division of Geological & Geophysical Surveys)

Approaches to Implementing OGC Web Map Services
By Ryan Clark (Arizona Geological Survey)

Creation of Digital Geologic Data for Pecos National Historical Park
By Andrea Croskrey and Georgia Hybels (National Park Service, Geologic Resources Division)

Converting Geologic Maps from Paper to Vector Format
By Richard B. Davis, Mark Steltenpohl, and Luke J. Marzen (Auburn University)

BeeGIS – a new open source and multiplatform mobile GIS
By Mauro De Donatis and Andrea Antonello (University of Urbino), Luca Lanteri (ARPA Piemonte), and Sara Susini (University of Urbino)

Demonstration of the Alluring Experience of Interactive Pen-On-Screen Mapping
By Mary DiGiacomo-Cohen (U.S. Geological Survey)

An Atlas of Unconventional Petroleum Resources in the Continental United States
By Evan Fedorko, Eric Hopkins, Frank Lafone, Denyse Wyskup, Kurt Donaldson, and Xiannian Chen (West Virginia University)

Database of the Geologic Map of North America
By Christopher P. Garrity and David R. Soller (U.S. Geological Survey)

Overcoming Cartographic and Technical Challenges in Developing an Interactive Mapping System for the Appalachian Basin Tight Gas Reserviors Project
By Sarah Gooding, Susan Pool, John Bocan (West Virginia Geological and Economic Survey)

Ohio Underground Mine Map Georeferencing Project
By Paul D. Hoeffler and Christopher P. Gordon (Ohio Division of Geological Survey)

A Geologic Resources Inventory of Our National Parks
By Ronald D. Karpilo, Stephanie A. O'Meara, Trista L. Thornberry-Ehrlich, Heather I. Stanton, and James R. happell (Colorado State University)

Minnesota Geological Survey information systems
By Richard Lively and Harvey Thorleifson (Minnesota Geological Survey)

New GIS tools for mapping Ohio Lake Erie Coastal Erosion Areas
By James McDonald, Paul Harbulak (Ohio Division of Geological Survey), and Scudder D. Mackey (Habitat Solutions NA)

Landscape Visualization through Lidar for Natural Stream Design
By Janette McNeer (Canaan Valley Institute)

Legacy Maps to GIS Vector Data -- Enabling Printing and Other Digital Applications
By David Mecklenburg (Techna-Graphics, Inc.)

Development of an ArcGIS map template to support standard geologic map production in Kentucky
By Mike Murphy (Kentucky Geological Survey)

NCGMP09 – a proposed standard format for digital publication of geologic maps
By National Geologic Map Database Project and Pacific Northwest Geologic Mapping Project (U.S. Geological Survey)

The OGC Catalog Service for the Web – what is it and how can we use it?
By Stephen M. Richard (Arizona Geological Survey)

Feature Extraction from High-Resolution Lidar – The Next Generation of Base Maps
By Jed Roberts, Sarah Robinson, Mathew Tilman, John English, Ian Madin, Rudie Watzig, and Bill Burns (Oregon Department of Geology and Mineral Industries)

The Cookie Cutter: a method for obtaining a quantitative 3D description of glacial bedforms
By Mike J. Smith (Kingston University, U.K.), James Rose (University of London), and Michael B. Gousie (Wheaton College, USA)

Map Database for Surficial Materials in the Conterminous United States
By David R. Soller, Marth C. Reheis, Christopher P. Garrity, and Darren R. Van Sistine

The National Geologic Map Database
By David R. Soller and Nancy R. Stamm (U.S. Geological Survey)

Surficial Material and Bedrock Geologic Mapping at the Missouri Department of Natural Resources, Division of Geology and Land Survey
By Edith Starbuck (Missouri Department of Natural Resources, Division of Geology and Land Survey)

Building an Enterprise Geotechnical Database to Support Geologic Mapping Activities

By Gerald A. Weisenfluh[1] and Bill Broyles[2]

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Lexington, KY 40506-0107
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email: *bill.broyles@ky.gov*

Introduction

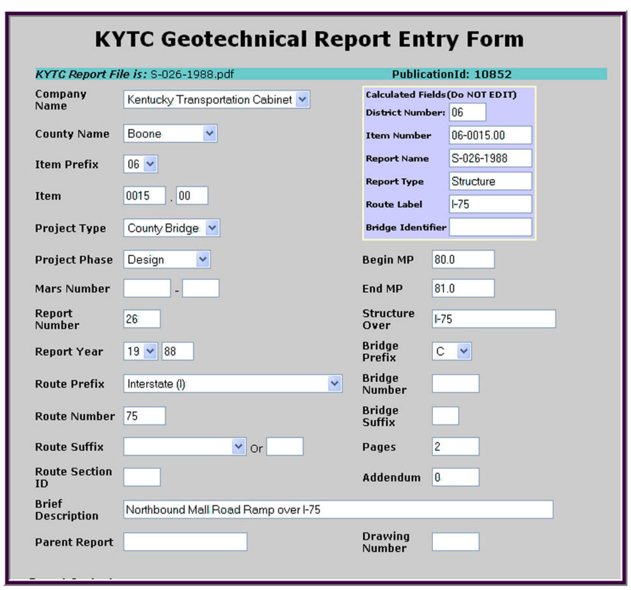
The Geotechnical Branch of the Kentucky Transportation Cabinet (KYTC) employs engineers and geologists to prepare design plans for roadway cuts, fills, and associated structures. Almost all projects involve site investigations that require drilling, sampling, and testing of geologic materials, including rock and soil. These data are reviewed by project staff, and standard engineering practices are used to create design drawings and recommendations for construction work. Drawings are prepared in CAD software and then combined with text documents to produce the final issued reports. Historically, the reports were produced as paper documents, and approximately 6,000 were filed in the Branch library. Supporting data, such as drillhole logs and lab analysis results, were loosely and inconsistently filed by county of location.

Public access to the reports, mainly by engineering consulting firms, was through verbal or written requests; however, there was no catalog of projects from which to identify reports of interest. Branch staff would respond to requests by making copies of reports or by scanning them into electronic files. Supporting data were generally not released because they were not easily accessible. Reductions in staffing levels at KYTC made it increasingly difficult to provide this information, and the system was vulnerable to losing important historical records.

In 2006, KYTC approached the Kentucky Geological Survey (KGS) for assistance with transitioning their records system from paper to electronic format. KGS had extensive experience with similar document conversion processes and had a Web system for disseminating geologic information. KGS geologists would benefit from easier access to the KYTC data for geologic mapping projects, since the KYTC project reports contain information about depth to bedrock, soil properties and classifications, rock descriptions and physical properties, water table data, and fracture measurements. KYTC would benefit from a reduced effort for distributing their data and could save significant financial resources by reusing drillhole data and analyses from historical projects. A 3-year program was initiated; the objectives were to make all historical reports available to the public through a Web service, create a Web-based management system for tracking the activities and characteristics of future projects, develop a software system for entering borehole and lab analyses into a relational database, and serve these supporting data to the public on the Web.

Archiving Legacy Geotechnical Reports for Web Distribution

The first phase of the project dealt with scanning, cataloging, and distributing the historical reports. KGS developed a database and corresponding data entry form based on interviews with KYTC staff familiar with the content of the reports. The goal was to attribute those characteristics that would be likely search criteria. Figure 1 shows the upper part of the form, which includes information about who conducted the geotechnical study, the location of the study in reference to the transportation network, what type of construction activity it was related to, when it was done, and an assortment of identifiers that relate to the Cabinet's central tracking database of road plans. To minimize typing errors and inconsistent entries, pull-down menus with standard lists were implemented, validation rules were applied where appropriate, and formatting of certain concatenated text values was done programmatically. Administrative functions were designed into the form so that users could update the interface (for example, to add new values to pull-down menus) without the assistance of a programmer. Figure 2 shows the lower part of the form, where contents of the report are described; this information was specified by the KYTC engineers and geologists to facilitate finding reports that deal with specific topics or engineering practices. Check-box controls were used to speed the data-entry process. A free text field was included to add items not covered on the lists, and periodically these nonstandard items were reviewed, and some were eventually included as standard check boxes.


KYTC Geotechnical Report Entry Form

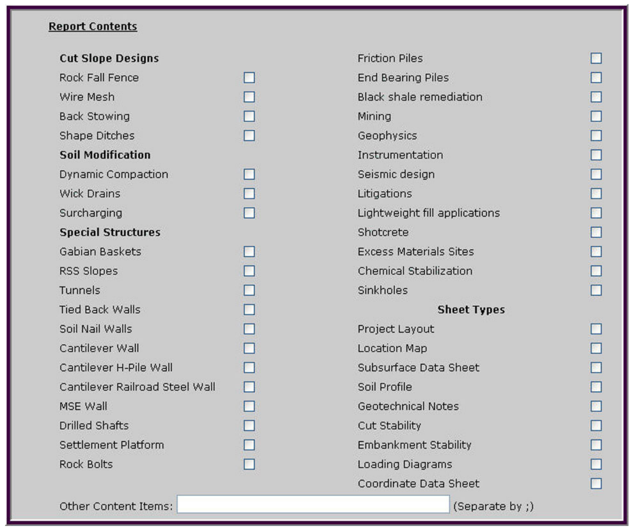
KYTC Report File is: S-026-1988.pdf PublicationId: 10852

Company Name: Kentucky Transportation Cabinet
County Name: Boone
Item Prefix: 06
Item: 0015 . 00
Project Type: County Bridge
Project Phase: Design
Mars Number: -
Report Number: 26
Report Year: 19 88
Route Prefix: Interstate (I)
Route Number: 75
Route Suffix: Or
Route Section ID:
Brief Description: Northbound Mall Road Ramp over I-75
Parent Report:

Calculated Fields(Do NOT EDIT)
District Number: 06
Item Number: 06-0015.00
Report Name: S-026-1988
Report Type: Structure
Route Label: I-75
Bridge Identifier:

Begin MP: 80.0
End MP: 81.0
Structure Over: I-75
Bridge Prefix: C
Bridge Number:
Bridge Suffix:
Pages: 2
Addendum: 0
Drawing Number:

Figure 1. Upper part of project data-entry form, showing the variety of descriptive information stored for each report.


Report Contents

Cut Slope Designs
Rock Fall Fence
Wire Mesh
Back Stowing
Shape Ditches
Soil Modification
Dynamic Compaction
Wick Drains
Surcharging
Special Structures
Gabian Baskets
RSS Slopes
Tunnels
Tied Back Walls
Soil Nail Walls
Cantilever Wall
Cantilever H-Pile Wall
Cantilever Railroad Steel Wall
MSE Wall
Drilled Shafts
Settlement Platform
Rock Bolts
Friction Piles
End Bearing Piles
Black shale remediation
Mining
Geophysics
Instrumentation
Seismic design
Litigations
Lightweight fill applications
Shotcrete
Excess Materials Sites
Chemical Stabilization
Sinkholes
Sheet Types
Project Layout
Location Map
Subsurface Data Sheet
Soil Profile
Geotechnical Notes
Cut Stability
Embankment Stability
Loading Diagrams
Coordinate Data Sheet

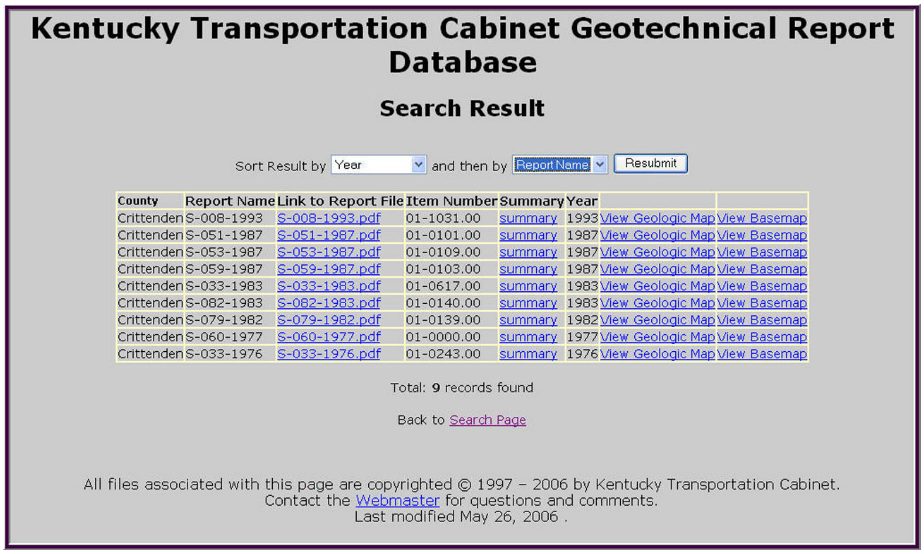
Other Content Items: (Separate by ;)

Figure 2. Lower part of project data-entry form, showing check-box contents that can be associated with a report.

Two other key elements were included at the suggestion of KGS. The first was the ability to assign one or more geologic units to a report. A search form was designed to look up standard stratigraphic names from the KGS geologic mapping database and translate them to alpha-numeric codes. The second allows for locating KYTC projects on a geographic base. Although many projects had geographic descriptions, such as route numbers and milepoint designations, these are not easily translated to geographic coordinates and moreover can change when roads are realigned. KGS developed an Internet map service that included a function to zoom to route milepoints or road intersections so that Branch staff could verify the project location on a topographic or photographic map base. Once the location was determined, a tool was used to define a bounding rectangle for the project, and the coordinates for that rectangle were added to a database table and its primary key was assigned to the report. This facilitated both drawing the project extents on a map as well as searching for reports using geographic criteria. A second way of locating projects was implemented for recent work in which lists of surveyed hole locations were available. These lists could be uploaded to the map service, posted for verification, and then used to define the project extent.

At the end of each data-entry session, the electronic report is selected on the user's computer; the report is uploaded to the KGS Web server for public dissemination and the attribute data are submitted to the database. Public access to these data is provided by an active server pages (ASP) Web service hosted by KGS (*http://kgs.uky.edu/kgsweb/KYTC/search.asp*). Users can search for reports by any combination of attributes that are included in the database. The result of the search (fig. 3) is a simple list of projects identified by county of origin, date of completion, project number, and KYTC item number that relates to the State's 6-year roadway plan. A number of links (formatted in blue) are also provided. One is to a summary page for the project giving more detailed information about the report and another is to the online version of the report. Two other links lead to Internet maps zoomed to the extent of the project—one a topographic map with other transportation information provided and the second showing the geologic context of the project with access to a variety of KGS geologic site data and descriptions (fig. 4).

The development of this phase of the project and the scanning of documents began in late 2006, and all the historical reports were cataloged and publicly available by fall of 2007.


Kentucky Transportation Cabinet Geotechnical Report Database

Search Result

Sort Result by Year and then by Report Name Resubmit

County	Report Name	Link to Report File	Item Number	Summary	Year		
Crittenden	S-008-1993	S-008-1993.pdf	01-1031.00	summary	1993	View Geologic Map	View Basemap
Crittenden	S-051-1987	S-051-1987.pdf	01-0101.00	summary	1987	View Geologic Map	View Basemap
Crittenden	S-053-1987	S-053-1987.pdf	01-0109.00	summary	1987	View Geologic Map	View Basemap
Crittenden	S-059-1987	S-059-1987.pdf	01-0103.00	summary	1987	View Geologic Map	View Basemap
Crittenden	S-033-1983	S-033-1983.pdf	01-0617.00	summary	1983	View Geologic Map	View Basemap
Crittenden	S-082-1983	S-082-1983.pdf	01-0140.00	summary	1983	View Geologic Map	View Basemap
Crittenden	S-079-1982	S-079-1982.pdf	01-0139.00	summary	1982	View Geologic Map	View Basemap
Crittenden	S-060-1977	S-060-1977.pdf	01-0000.00	summary	1977	View Geologic Map	View Basemap
Crittenden	S-033-1976	S-033-1976.pdf	01-0243.00	summary	1976	View Geologic Map	View Basemap

Total: 9 records found

Back to Search Page

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Contact the Webmaster for questions and comments.
Last modified May 26, 2006 .

Figure 3. Example project search result page with links to the online report and to Internet maps that show the geographic and geologic context of the projects.

Managing Geotechnical Project Activities

Once phase I was accomplished, the next phase of the project addressed management of active projects. In many ways this was similar to cataloging historical reports, except for the timing of data entry. Rather than beginning with a finished report, new project data are entered over time as the project work proceeds. Once the project is complete, the final report is issued and uploaded to the system and the project status is changed from active to complete, making the information available to the public. The cataloging program was modified to reflect this workflow, and an additional set of functions was added to track project activities. These included a form to record the dates of completion for project milestones such as completion of drilling or issuance of various documents. This is an extremely useful function for the Branch manager, because from 100 to 200 projects may be active at a given time. Standard reports were designed for various aspects of projects, such as those related to a geologist's or driller's activities, or specific types of projects such as landslide mitigations or structural designs. The manager can

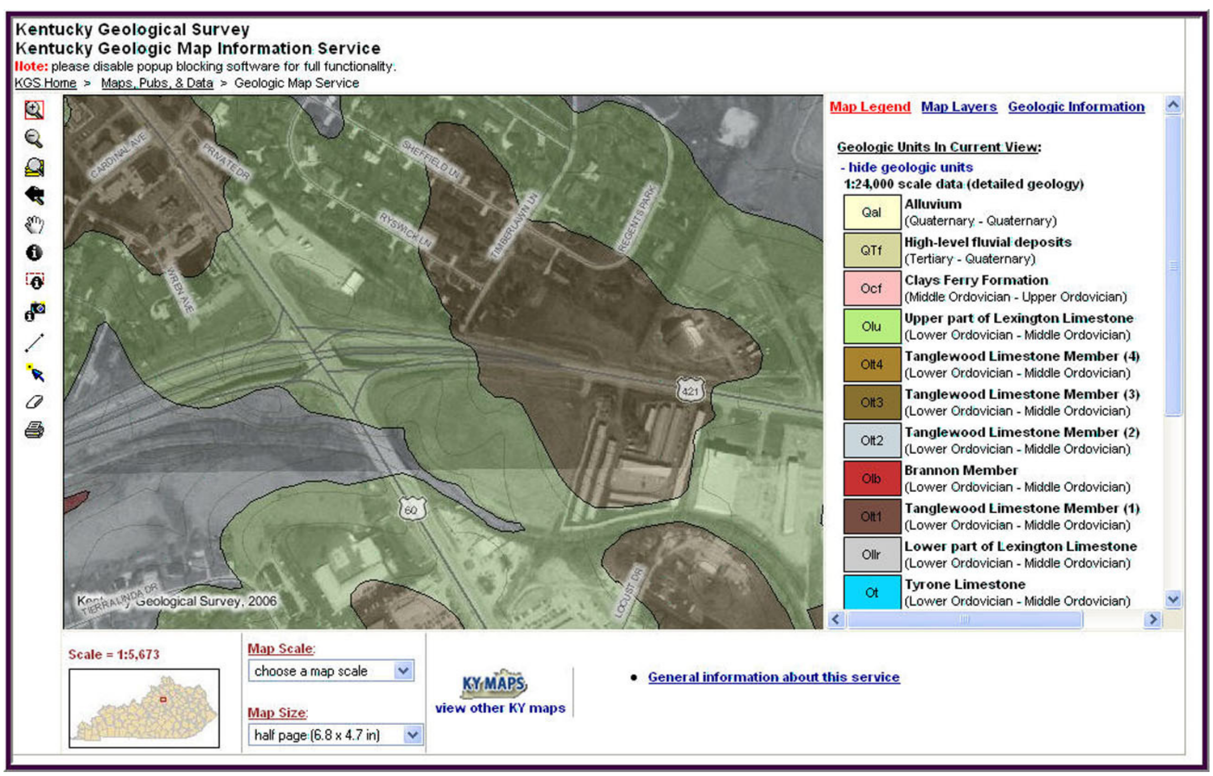


Figure 4. Geologic map zoomed to the extent of a linked project, showing formation contacts along a major route intersection.

now create a report to quickly assess the status of activities to identify impediments to project completion.

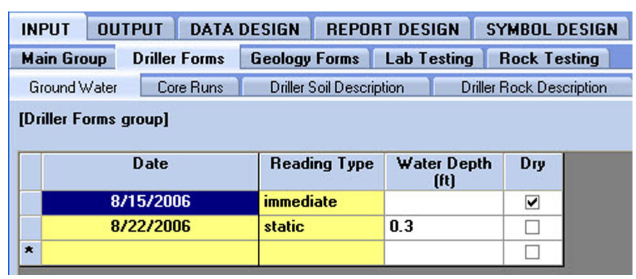
Another function was added that analyzes the catalog to find relationships between projects. For example, planning projects usually precede roadway designs, and a number of bridge and culvert structure designs may relate to a roadway project. This function builds the complete hierarchical relationship tree beginning with any specified project and looking upward and downward in the tree.

Building an Enterprise Drillhole Database

Almost every KYTC geotechnical study involves drilling holes—rock soundings, soil sample holes, and rock coreholes—to obtain samples for material testing and to visually assess those materials. Structure projects typically require from 2 to 12 holes, whereas roadway projects may have as many as 300 holes. Over 2,300 holes were drilled in 2007, and more than half of those had samples that were laboratory tested. Historically, such drillhole data were used solely for the project on which they were obtained, but given the substantial costs of acquiring the data, KYTC was interested in developing a database that would enable them to reuse data for future projects conducted at nearby locations. A historical database of drilling and testing data would also facilitate characterization of rock and soil intervals over larger areas than are typically studied for site assessments—information that could greatly enhance geologic and soils mapping of Kentucky. Therefore, the third phase of this project was intended to develop an enterprise software system for storing drillhole data and a Web interface for exploring the data to find holes that could be useful for new design projects or for regional analysis.

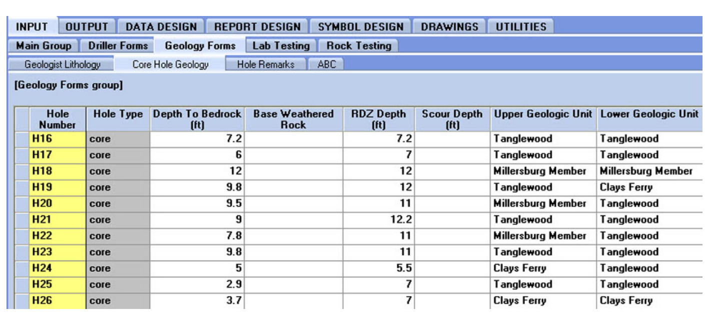
Geotechnical projects are conducted by teams that include engineers, geologists, lab technicians, drillers, and CAD operators. Standards for data collection, analysis, and reporting have been developed over the years at KYTC to maintain consistency in results and report formats. The design requirements for the data entry system included forms that modeled the workflow of team members, and extensive controls to adhere to standard vocabulary, methods, and calculations. Another objective was to minimize data entry by providing functions to import data from external databases, using pull-down menus, and by calculating numerical values programmatically wherever possible. The gINT software suite (*http://www.gintsoftware.com*) was selected to develop the data-entry application because of its capabilities for customization and powerful report development modules. gINT uses Microsoft Access for its data storage format and Visual Basic for Applications for program customization. It includes modules for building data-entry applications, for designing text or graphical output, and for import and export of data. At the time of development for this project, gINT software did not have the capability to build and maintain an enterprise database. It was designed for the consulting industry, which typically performs separate, discrete projects; therefore, each project's data are stored in a separate database. Consequently, PLog Enterprise (*http://www.dataforensics.net*) was acquired to convert the gINT projects to a SQLServer database for permanent archive and to facilitate the most efficient mechanism of Web distribution.

Project description information is already stored in the project management system described above; therefore, it can be imported directly into gINT to initiate a new database. Similarly, KYTC surveyors are required to prepare a list of hole locations in a standard format so that these data can be imported as well. Once these sets of data are imported, the project manager adds other details about the characteristics of each hole to prepare it for further data entry by team members. Drillers enter information about groundwater levels, core recovery, rock intervals, and soil sample intervals. An example form (fig. 5) shows entry of both immediate and static groundwater readings for a hole. Geologists enter the lithologic data for coreholes and a variety of rock assessments that depend on the type of project. Figure 6 shows depth to rock and rock disintegration zone (RDZ), a parameter related to weathering of rock material, along with geologic unit designations. Finally, lab personnel enter all the results of soil and rock analyses, including moisture, size analysis, California bearing ratio tests, and a variety of strength tests. Figure 7 shows the summary table for soil classifications, in which raw size data are used to derive a variety of soil classifications required for engineering designs.


INPUT | OUTPUT | DATA DESIGN | REPORT DESIGN | SYMBOL DESIGN
Main Group | Driller Forms | Geology Forms | Lab Testing | Rock Testing
Ground Water | Core Runs | Driller Soil Description | Driller Rock Description
[Driller Forms group]

Date	Reading Type	Water Depth (ft)	Dry
8/15/2006	immediate		☑
8/22/2006	static	0.3	☐
*			☐

Figure 5. Data-entry form in gINT software, for groundwater readings.


INPUT | OUTPUT | DATA DESIGN | REPORT DESIGN | SYMBOL DESIGN | DRAWINGS | UTILITIES
Main Group | Driller Forms | Geology Forms | Lab Testing | Rock Testing
Geologist Lithology | Core Hole Geology | Hole Remarks | ABC
[Geology Forms group]

Hole Number	Hole Type	Depth To Bedrock (ft)	Base Weathered Rock	RDZ Depth (ft)	Scour Depth (ft)	Upper Geologic Unit	Lower Geologic Unit
H16	core	7.2		7.2		Tanglewood	Tanglewood
H17	core	6		7		Tanglewood	Tanglewood
H18	core	12		12		Millersburg Member	Millersburg Member
H19	core	9.8		12		Tanglewood	Clays Ferry
H20	core	9.5		11		Millersburg Member	Tanglewood
H21	core	9		12.2		Tanglewood	Tanglewood
H22	core	7.8		11		Millersburg Member	Tanglewood
H23	core	9.8		11		Tanglewood	Tanglewood
H24	core	5		5.5		Clays Ferry	Tanglewood
H25	core	2.9		7		Tanglewood	Tanglewood
H26	core	3.7		7		Clays Ferry	Clays Ferry

Figure 6. Form for entering a geologist's rock evaluations in gINT software.

Plus #4 (%)	Gravel (%)	Coarse Sand (%)	Fine Sand (%)	Silt (>.002) (%)	Clay (<.002) (%)	Colloid (<.001) (%)	AASHTO Symbol	AASHTO Group Index	USCS Symbol	USCS Group Name
0.0	0.0	6.0	5.6	39.1	49.3	42.4	A-7-6	(29)	CH	FAT CLAY
0.0	0.0	2.2	4.9	41.6	51.4	40.5	A-7-6	(36)	CH	FAT CLAY
10.8	18.0	11.4	8.7	38.8	23.1	16.5	A-6	(14)	CL	LEAN CLAY
0.0	0.0	5.5	7.1	49.5	37.8	27.8	A-7-6	(23)	CL	LEAN CLAY
24.9	24.9	16.7	13.9	34.3	10.3	7.0	A-4	(4)	CL-ML	SILTY CLAY

Figure 7. Soil classification form in gINT software, showing soil classifications calculated from raw input data.

Each data-entry form represents a table in the Access database and may have one or more Visual Basic subroutines assigned that are executed at different times relative to saving the dataset. These procedures are used extensively to validate data entry, to initialize new records in related tables, to perform calculations, and to issue error messages.

Use of the gINT software product allowed KYTC to maintain standardization throughout the database. It also provided a mechanism to enforce standards for projects that are subcontracted to consultants. All consultants are required to use the same software, and KYTC supplies each vendor with a preformatted database that includes the list of holes to be drilled. The contractors enter the data when holes are completed and return the gINT database to KYTC at the end of the project.

Since the gINT application was completed in early 2007, 200 projects with 3,200 holes have been entered and archived in the KGS SQLServer database using the PLog software. Currently, a system is being implemented that will allow KYTC personnel to remotely upload the completed project files into the KGS database.

The final task of this phase was to develop Web services to search the drillhole database and return a variety of tabular and formatted reports. These services were developed using ASP and are available to the public (*http://kgs.uky.edu/kgsmap/gINT/gINTSearch.asp*). Figure 8 is the search form that permits queries ranging from any information for holes drilled by a specific project, to all holes containing a specified soil type. The criteria can be geographic, stratigraphic, the presence of specific soil or rock types, or particular kinds of analyses. The result of a query is a list of all projects that contain at least one hole that met the criteria (fig. 9). The project summary line contains a link to the final report as well as a hole summary report that contains descriptive information and geotechnical values such as depth to rock and allowable bearing capacity. Each project line can be expanded to show a list of holes, and each hole has a page containing links to available reports such as the geologist's log and any soil or rock test results (fig. 10).

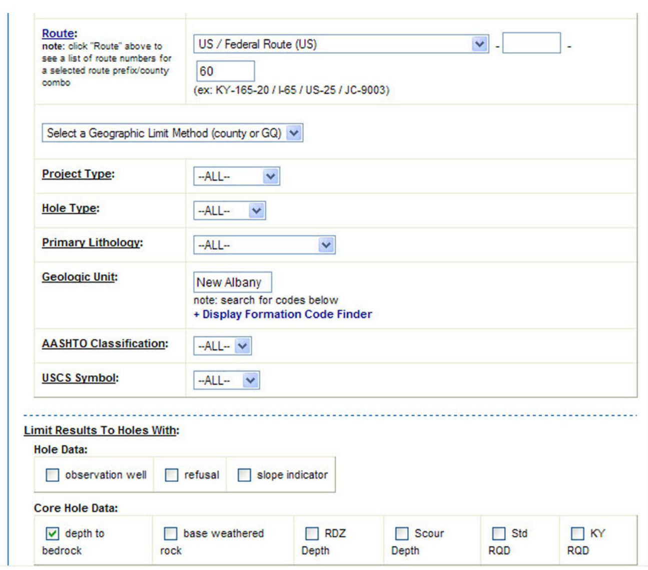
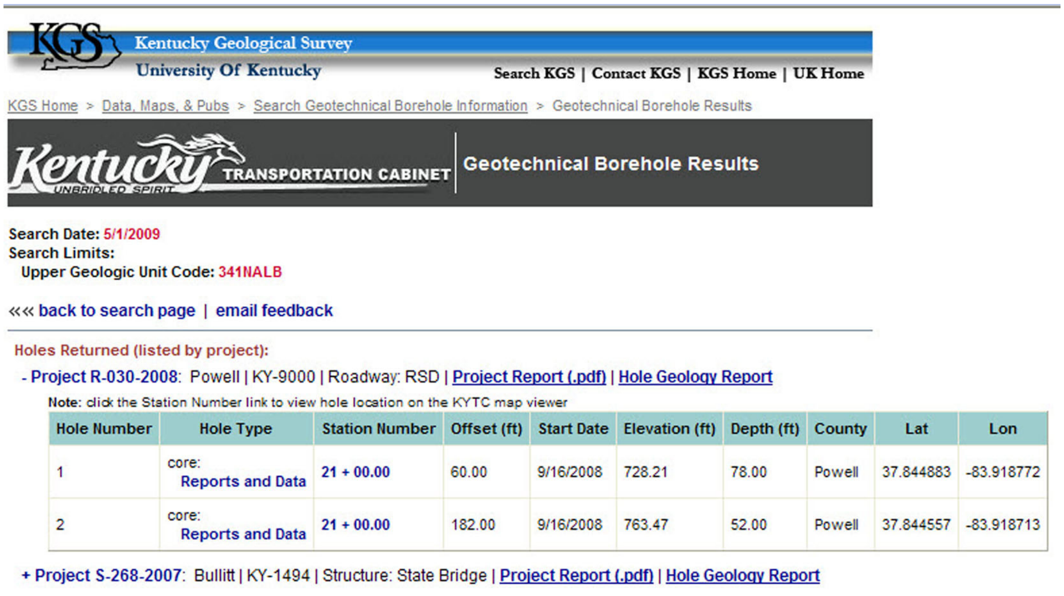


Figure 8. Online search form for finding holes that contain specified kinds of information.



Kentucky Geological Survey
University Of Kentucky
Search KGS | Contact KGS | KGS Home | UK Home

KGS Home > Data, Maps, & Pubs > Search Geotechnical Borehole Information > Geotechnical Borehole Results

Kentucky Unbridled Spirit TRANSPORTATION CABINET | Geotechnical Borehole Results

Search Date: 5/1/2009
Search Limits:
Upper Geologic Unit Code: 341NALB

«« back to search page | email feedback

Holes Returned (listed by project):

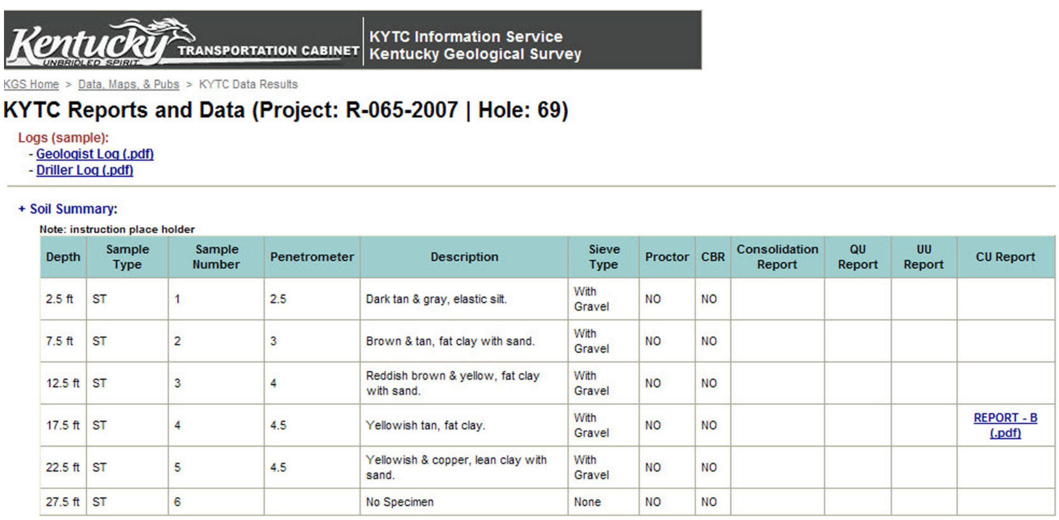
- Project R-030-2008: Powell | KY-9000 | Roadway: RSD | Project Report (.pdf) | Hole Geology Report

Note: click the Station Number link to view hole location on the KYTC map viewer

Hole Number	Hole Type	Station Number	Offset (ft)	Start Date	Elevation (ft)	Depth (ft)	County	Lat	Lon
1	core: Reports and Data	21 + 00.00	60.00	9/16/2008	728.21	78.00	Powell	37.844883	-83.918772
2	core: Reports and Data	21 + 00.00	182.00	9/16/2008	763.47	52.00	Powell	37.844557	-83.918713

+ Project S-268-2007: Bullitt | KY-1494 | Structure: State Bridge | Project Report (.pdf) | Hole Geology Report

Figure 9. Primary search result report, listing all projects that met the hole search criteria.



Kentucky Unbridled Spirit TRANSPORTATION CABINET | KYTC Information Service Kentucky Geological Survey

KGS Home > Data, Maps, & Pubs > KYTC Data Results

KYTC Reports and Data (Project: R-065-2007 | Hole: 69)

Logs (sample):
- Geologist Log (.pdf)
- Driller Log (.pdf)

+ Soil Summary:

Note: instruction place holder

Depth	Sample Type	Sample Number	Penetrometer	Description	Sieve Type	Proctor	CBR	Consolidation Report	QU Report	UU Report	CU Report
2.5 ft	ST	1	2.5	Dark tan & gray, elastic silt.	With Gravel	NO	NO				
7.5 ft	ST	2	3	Brown & tan, fat clay with sand.	With Gravel	NO	NO				
12.5 ft	ST	3	4	Reddish brown & yellow, fat clay with sand.	With Gravel	NO	NO				
17.5 ft	ST	4	4.5	Yellowish tan, fat clay.	With Gravel	NO	NO				REPORT - B (.pdf)
22.5 ft	ST	5	4.5	Yellowish & copper, lean clay with sand.	With Gravel	NO	NO				
27.5 ft	ST	6		No Specimen	None	NO	NO				

Figure 10. Summary of soil samples for a single drillhole, with links to online reports containing analytical results.

Integrating Geotechnical Data with Geologic Maps

Future additions to this system will include search functions to return tabulated test results of specified parameters for regional analysis and modeling. For example, all strength tests for clay soil types could be extracted to facilitate comparison to mapped soil or geologic units. Because all the holes are geographically referenced in the database, it will be possible to integrate information from these holes with the statewide geologic map database developed from Kentucky's 7.5-minute geologic map series. This online, interactive geologic map site (*http://kgs.uky.edu/kgsmap/KGSGeology*) has the ability to display derivative classifications of geologic units. The availability of this extensive geotechnical data will provide opportunities to add new classifications that will facilitate the use of geologic maps by engineers.

A Practitioner's Guide to Managing Geoscience Information

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Abstract

In the United Kingdom, the Natural Environment Research Council manages its scientific data holdings through a series of Environmental Data Centres covering Atmosphere, Bioinformatics, Earth Sciences, Earth Observation, Hydrology, Marine Science, and Polar Science (*http://www.nerc.ac.uk/research/sites/data/*). Within the Earth Science sector, the National Geoscience Data Centre (NGDC, *http://www.bgs.ac.uk/services/ngdc/about.html*), a component of the British Geological Survey (BGS), is responsible for managing the geosciences data resource. The purpose of the NGDC is to maintain the national geoscience database and to ensure efficient and effective delivery by providing geoscientists with ready-to-access data and information that is timely, fit for purpose, and in which the user has confidence. The key benefits that NERC derives from this approach are

- Risk reduction,
- Increased productivity, and
- Higher quality science.

The paper briefly describes the key benefits of managing geoscientific information effectively and describes how these benefits are realised within the NGDC and BGS.

Introduction

Worldwide, Geological Survey Organisations (GSO) have three principal resources. These are

- The expert work force that they employ,
- The facilities to which they have access, and
- The scientific information holdings that they maintain.

This can be likened to a three-legged stool. When all three legs are strong, the stool functions effectively. When any individual leg is weak or missing the whole stool is useless, even if two out of three legs are functioning correctly. Each of these resources needs to be managed. In many GSOs there are professional personnel mangers who manage the staff and there are professional facilities managers to manage the buildings, laboratories, ships, and so forth. However, the management of the third leg of the stool, information management, is often overlooked. Information is often regarded as 'personal' property and not managed as an organisational asset, so that it is either lost or becomes degraded due to lack of basic maintenance.

The purpose of information management in a GSO is to maintain the national geoscience database and to ensure efficient and effective delivery by providing geoscientists with ready-to-access data and information that is timely, fit for purpose, and engenders confidence in the user.

The main drivers for information management are to

- Reduce staff effort in finding data,
- Make quality data available to staff and customers,
- Facilitate collaboration across and between GSOs and other environmental science organisations,
- Improve access to the unique information resources,
- Inform management decisions, and

- Allow corporate implementation of standards and establish best practice.

The benefits that accrue to a GSO through good information management are

- Risk reduction
  - Reduce legislative compliance risk,
  - Reduce litigation risk,
- Increased productivity, and
- Better science.

These benefits will be discussed below.

Risk Reduction

The information-related risks that a GSO faces vary from country to country. The risk level depends upon the legal framework relating to information held by public sector organisations and the risks of litigation that follow the dissemination of information or the provision of advice. The Lofthouse Colliery (coal mine) Disaster is an illustrative example of such a risk. On the 21st March 1973, long-wall advance coal mining was taking place at the Lofthouse Colliery in West-Yorkshire, England. The mining machine cut into unknown old workings of an abandoned colliery called Low Laithes. There was a sudden and catastrophic inrush of water from the old workings that flooded part of the Lofthouse Colliery. Seven miners were killed by the inrush and the colliery was closed shortly afterwards. It transpired at the subsequent enquiry that there was evidence of the existence of the abandoned mine workings held by both the Institute of Geological Sciences (renamed the British Geological Survey in 1984) and other national bodies. However, only a few people in these organisations were aware of the existence of the information and they were unaware of the approaches to their organisations by the mining company that was planning the development of the new face at Lofthouse Colliery. The subsequent report into the disaster by the Chief Inspector of Mines and Quarries recommended the creation of a searchable catalogue of information relating to mining records held by the Institute of Geological Sciences. The Lofthouse Colliery disaster highlighted some of the risks that an organisation is exposed to when it has a limited understanding of the information it holds.

In general the risk can be reduced by

- Knowing what information is held by a GSO,
- Managing that information as an asset,
- Knowing the quality of the information, and
- Preserving a record of the evidence used to make decisions or to provide advice.

Know the Data Holdings

It is essential that an organisation know what their data holdings are. It is both good business practice and a key element of a risk reduction strategy. Many countries have introduced some form of Freedom of Information legislation or laws that provide citizens with access to environmental information relating to their communities. Other legislation promotes the reuse and repurposing of information collected by the public sector organisations, which may include GSOs. Much of this legislation is predicated on the assumption that public sector organisations have a clear understanding of the legacy information that they have collected in the past and the information that they continue to collect at present. It is assumed that an information asset register is available or can be rapidly created to meet the legal requirement. This may not be a trivial task, and may consume considerable resources.

The information asset register requirements of most counties will be met by compiling ISO 19115 geospatial metadata (British Standard ISO 19115:2003). However, such an information asset register only provides a top-level view of the data. More detailed metadata will be required to develop a comprehensive understanding of the data holdings. Proactive publication of information asset registers through metadata aggregation services can further reduce risk.

Where resources permit, it is valuable to create digital indexes, or spatially enabled digital indexes, that show the distribution of individual data points within a dataset. This greatly improves the usability of a data holding and promotes its future reuse and repurposing.

Managing the Information Holdings as an Asset

There are two ways to manage information within an organisation: information can be managed as a liability or as an asset. The first way is to manage organisational information as a liability. Nobody wants to take responsibility for the liability, and managers are reluctant to invest time and budget. Information is stored in the cheapest possible ways and is difficult to access. This leads to a downward spiral resulting in a loss of control of the organisation's information resource. The alternative approach is to manage information as an organisational asset and to use standard asset management approaches. This involves assigning management responsibilities with clear resources and goals.

Once information assets have been identified, their active management is essential. The phrase "information entropy" was coined by Michener and others (1997) to describe the tendency for stored information to become more disordered over time. The British Geological Survey has adopted an asset-based approach to information management. All datasets have an ISO 19115 metadata record created for the dataset. These metadata records are used as the organisation's Information Asset Register. The metadata includes the name of the manager who is responsible for the dataset. The manager's first responsibility is to produce a data management plan for the dataset and to indicate the resources required. Where appropriate, detailed data management procedures are developed to ensure that the dataset is properly maintained and developed. The manager is are also responsible for working with the Intellectual Property Rights manager to ensure that these rights are understood and protected.

Once there is a clear understanding of the information assets of an organisation, decisions can be made about resource allocations. The U.S. Department of Transportation has developed an Asset Management Primer (U.S. Department of Transportation, 1999). This is a process for determining investments and priorities for the management of physical assets for which it is responsible (for example, bridges). With a little adaption, these processes can be transferred from physical infrastructure assets to information assets (see figure 1). Typical questions that should be asked include

- What is the goal of managing the information asset?
- What is the purpose of the information asset?
- What is the quality of the information asset?
- What is the lineage of the information asset?
- How can we preserve the information asset?
- How often is the information asset used?
- What is the cost of preserving the information asset?
- What are the consequences of not maintaining the information asset?
- What is the priority of the individual information asset?

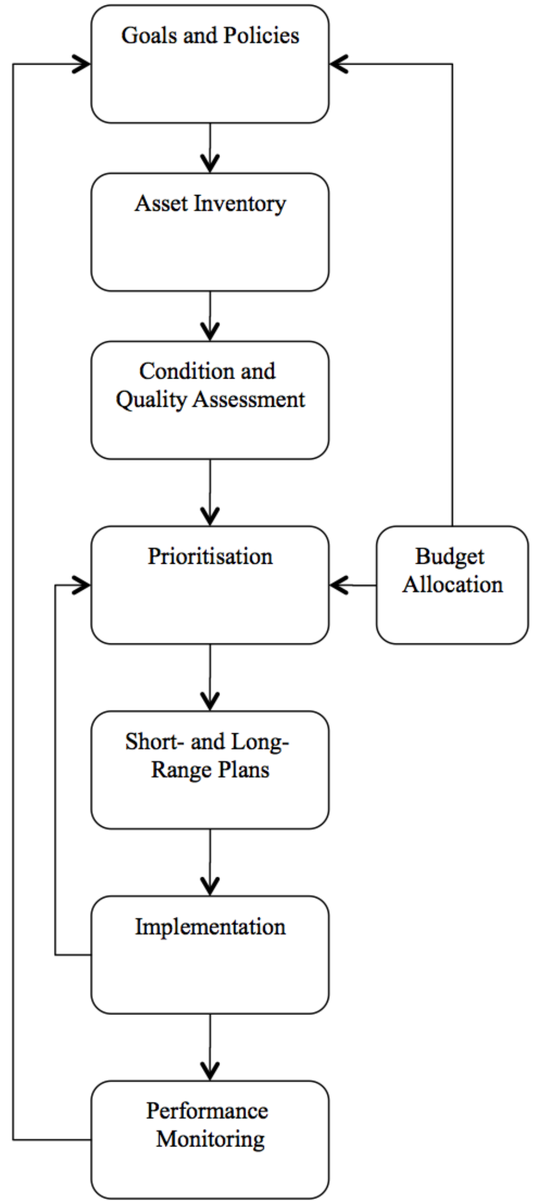

Figure 1. Information Asset Management Primer (from U.S. Department of Transportation, 1999).

There are risks associated with holding information assets that others will reuse and repurpose. Given that quality is commonly defined as "fit for purpose," then reuse and repurposing of information assets will inevitably raise quality issues. Having a clear and well documented process by which management decisions are made helps to reduce the exposure to such risks.

The discipline of records management is informative for data management practitioners. The practice of data managers has been to retain everything by default. This is rapidly building an unsustainable legacy that will require addressing in the future. A records management practice of retention scheduling and review with these options is very attractive

i. Disposal,

ii. Retention for a further period with another review at the end, and

iii. Selection for permanent archiving.

Improve Quality

There are two elements to improving the quality of an information asset:

- Documenting the quality through accurate metadata; and
- Addressing known errors.

Metadata is a rich tool. It does so much more than just aiding discovery and identification of datasets. The true purpose of metadata is to allow a potential user of a dataset to assess whether it is fit for their intended purpose. Feineman (1992) identified eight dimensions of data management. These are:

- Accessibility
- Security
- Timeliness
- Accuracy
- Completeness
- Fidelity
- Lineage
- Quality.

These eight dimensions naturally fall into two groups: data management and data quality. The data management dimensions are accessibility, security, and timeliness, whilst the remaining five dimensions relate to data quality. Feineman's ideal for a high quality dataset was one that had exceptional completeness, accuracy, fidelity, and lineage. A comprehensive metadata record allows a potential user to make an accurate assessment of the quality of the datasets. As part of the metadata, a description of the accuracy is important. This should take the form of error limits, and where there are known errors these should be addressed and corrected.

Preserve the Evidence

GSOs produce a range of information-based products and services. These include reports, maps, models, geographical information systems, databases, and so forth. These are used by other organisations to make decisions, develop policy, or make commercial decisions. For this reason it is critical that GSOs preserve the information from which their products and services have been created. It is quite possible for advice provided decades beforehand to be questioned. GSOs therefore need to be able to reexamine the data sources and information used to prepare past products and services. The legal costs of defending past decisions can be considerable. The defense costs can increase considerably if the original data or information cannot be found or if provenance of the evidence is disputed. In terms of risk reduction, it is well worth ensuring that the evidence is preserved in an appropriate records management system.

It is worth noting that the risks associated with digital data appear higher than for paper records. Peritz (1986) noted:

> "…*the presumption of trustworthiness (of digital data) simply carries too much weight*...".

Whilst Tarter (1992) noted:

> *"(the) myth of machine infallibility seems to create a demand for higher standards of quality for machine readable data than for traditionally distributed information."*

It appears that once data have become digital they somehow are more trustworthy than mere analogue records. This may be a passing phenomenon, but it should encourage the custodians of digital data to manage their quality carefully.

Increased Productivity

Ready access to quality information is essential to scientists. If this is not available then scientists will spend time and effort searching for existing information and improving information quality when they have found it. In the worst case, they may expend resources reacquiring information that already exists. This is not a good use of their time or money. Discovery of information resources can be improved by creating appropriate metadata, a function that can be facilitated by junior staff. Many basic quality checking or quality improving operations can be automated or performed by junior staff, freeing scientists to add value to the information and create knowledge.

Various estimates have been made and studies conducted to quantify the effort that scientists expend in searching for and improving information quality. Two examples are cited below.

Peebler (1996) made the following observation:

> *“Lack of basic data integration costs the average E&P professional a considerable amount of time. According to various estimates geoscientists and engineers spend from 20% to 30% of their total project time searching for, loading, and formatting data. Obviously, significant productivity gains are still locked up in organizations that do not have level one integration.”*

In 2002 Shell International undertook a study showing that for new frontiers areas, Shell staff spent their time as follows:

- Finding data – 53 percent
- Archiving data – 9 percent
- Documenting the data – 15 percent
- Interpreting (adding value) – 23 percent.

Shell set goals to raise the time spent interpreting the data (adding value) to 46 percent, by reducing the time to find data to 30 percent (BGS, 2009).

Both studies suggest there is considerable potential to increase scientists’ productivity if they have ready access to quality information.

Better Science

Good information management contributes to improving the quality and reliability of scientific outputs in a number of ways:

- Preserving the evidence
- Reuse of existing information
- Repurposing of existing information.

Information collected during a scientific research project forms a key component of the record of that project. Should the results of the study be questioned in the future, the preserved record of the project can be reviewed to ensure that the conclusions and recommendations of the project remain valid or whether a reinterpretation is justified.

The information collected during a project can be reused at a later date. For example, information could be collected for a study area during a research project and preserved after the project is concluded. At a later date a new project undertakes a regional study, which reuses the data collected in a previous project and undertakes additional collection of information in other parts of the region. The opportunity to reuse existing information reduces the cost of the subsequent study.

Information collected for a specific purpose by a research project can be used for an entirely different purpose that was not envisaged when the original information was acquired. For example, the British Geological Survey routinely acquires borehole logs from site investigations; over the course of time, well over a million logs have been collected from across Great Britain. The original purpose of these boreholes was to gage the foundation conditions for a proposed building project. However, information contained within these borehole logs was aggregated to produce a national superficial sediment thickness model.

Conclusion

A range of significant benefits that can be realised through a well organised and well resourced information management programme. These benefits can only be realised through careful planning and implementation. Key elements of such a programme include:

- Creating metadata that enables the information resource to be discovered and the quality of that resource to be assessed.
- Digital indexes, that may be spatially enabled, created for key resources so that individual items within information can be located.
- Asset-based information practises are adopted so there is a clear plan for investment in specific information resources both in terms of business need and long-term preservation.

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Improving ArcGIS Workflow: Automation Using Visual Basic for Applications (VBA)

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Abstract

Many tasks associated with editing and quality checking (QCing) GIS datasets can be tedious, repetitive, and time consuming. Automation of some of these tasks, such as systematic panning around a map and semi-automated feature attribution, is very desirable. Using the Visual Basic for Applications (VBA) development environment, which is included and fully supported in ArcGIS, and the many free code resources available online, applications can be developed to automate and speed up these tasks. This paper covers (1) some basic information about programming in ArcGIS, (2) discussion of how to plan and budget time for scripting, and (3) a list of online resources used for VBA code reference, samples, and help.

Introduction to Automation and Scripting in ArcGIS

The ESRI ArcGIS software package has long had the ability to be customized by its users to produce innovative solutions to all sorts of problems. Whether it is overcoming a shortfall in the functionality of the original software, automating a repetitive task, or simply preparing a template or customized layer symbology or feature representation, there is almost always a way to create a tailored solution through one of the three common ways to customize ArcGIS. From the most basic to the most advanced, they are (1) layer definition files, styles, and map templates, (2) ModelBuilder process modeling and Python scripting, and (3) Visual Basic, C++, or Java scripting. While definition files and styles are useful for "visual automation," in other words, customization and replication of *representations* of feature symbology and labeling in map layers, they do not allow for the customization of *functions* (for example, geoprocessing) applied to features within ArcMap. Templates go a step further and allow users to customize a set of layers that are loaded automatically each time ArcMap is started, and they also permit storage of custom toolbars and macros. The second method of customization using ModelBuilder or Python begins to expose more robust automation in ArcGIS and gives users the ability to design scripts that can be used to automate the manipulation of features, their classes and their attributes. ModelBuilder is a component of ArcCatalog that lets the user drag-and-drop ArcToolbox functions into a window and assemble them in a flowchart-like fashion to string the output of one function to the input of the next until a final output is generated. For example, the user might need to repetitively select features from a layer based on an attribute, clip those features based on a feature in another layer, reproject those features, store them in a new feature class, and add them to the map display. Python scripting takes the power of these models a step further, allowing the user to add more advanced logic and iterative loops to process features based on more complex criteria. The third method, using Visual Basic (or VBA), C++, and Java scripting, is the most advanced and most robust form of customization. These programming languages have access to ArcObjects, which is the core of the ArcGIS application suite, and let the user create scripts that interact with the application directly as actions take place, as well as create customizations to the user interface. This paper will focus on the third segment of customization: use of VBA for creating custom tools for use in ArcMap.

ArcGIS, ArcObjects, and VBA

At the core of the ArcGIS application suite is a set of modules that provide access to all the functionality available in each component of the software package. This module set is called ArcObjects. ESRI defines ArcObjects as, "a set of platform-independent software components … that provides services to support GIS applications on the desktop" (ESRI Developer Network, 2009a). These software modules were developed within a framework that allows them to be used across platforms (Windows, Linux, and so forth), across applications (ArcMap, ArcCatalog, and so forth), and have their properties accessed by various programming languages. For more information about ArcObjects and ArcGIS software architecture, see the ArcGIS Resource Center Web site (*http://resources.esri.com/arcgisdesktop/*).

While there are many advantages to having such an open, modular architecture, one of particular interest is the ability to utilize these powerful modules at several levels of programming expertise. Since many GIS users have scientific backgrounds and are not native users, it can be a struggle for them to get over the steep learning curve of the GIS application itself, let alone getting into programming and application customization. But ArcGIS has an integrated programming environment in which the full power of ArcObjects is available: Visual Basic for Applications (VBA). As ESRI states: "It [VBA] provides a programming environment, the Visual Basic Editor (VBE), which lets you write a Visual Basic (VB) macro, then debug and test it right away in ArcMap or ArcCatalog. A macro can integrate some or all of Visual Basic's functionality, such as using message boxes for input, with the extensive object library that ArcMap and ArcCatalog expose" (ESRI Developer Network, 2009b).

Visual Basic is probably one of the easiest programming languages to learn, due to its relatively intuitive syntax and lack of visual clutter in the code. The VBE has many resources built in to help a novice user understand the code, including auto-complete when typing code for function properties (to avoid accessing inappropriate properties), as well as an object browser that explains object relationships and gives definitions of object properties. VBA can access global variables within the document, application, and operating system so the user can create hooks into the application that trigger actions based on what is taking place within the user environment. Users can create custom user interface forms visually using many of the same components available in larger, more robust programming environments such as VB .NET and Visual C++. Also, close relationships of VBA with VB 6 and VB .NET allow relatively easy migration of VBA code to VB Dynamic Link Library projects in those environments. The Visual Basic Editor interface and run-time debugging tools quickly and easily test and debug macros inside ArcMap and ArcCatalog without the worry of compiling and testing code in another environment. Finally, the single greatest advantage to VBA is the availability of thousands of code samples in the help system and on the Web that are ready to be cut, pasted, and run within the VBE environment without extensive programming experience on the part of the user. For more information about VBA and its functionality, see "Getting started with VBA" in the ArcGIS Desktop Help (*http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Getting_started_with_VBA*).

Script Design: Goals and Budgeting Time

A common misconception about programming is that it requires a computer science degree, and many years of training, for successful use. Another misconception is that it takes a lot of time to create a customization. The truth is that with the availability of so many examples and "canned" code on the Web, and in the help documentation of VBA, anyone can quickly create simple scripts to help automate a process in ArcGIS. The key points to remember are to *keep scripts simple* and that automations *save time in the long run*. Scripts do not need to be complex. They do not need to be polished bits of code with all the fail-safes that professionally coded applications have. They only need to be as functional as you need them to be, and once you get them working, you can continue to improve them and add more functionality or more robust error handling for use by a wider audience.

When tackling a scripting project, the first step is to clearly identify the goals of the automation. Again, this is a process of identifying the bare-bones functionality, then deciding what (if any) additional fail-safes or bonus features should be added if time allows. In most cases, the steps in the automation are exactly the same as if you were to do the process manually. Consider the following scenario from a script I designed to help with the attribution of features: structural symbols were digitized from a georeferenced scan of a paper map and needed to have the dip value and symbol type attributes added to each feature. If this were to be done manually, the process would go something like this, assuming the features had already been created: (1) start an edit session, (2) select the features that need attribution (select all or a subset), (3) open the attribute table or the Editor Attributes window and pan/zoom to the first feature, (4) type the value for the dip or the symbol type code into the appropriate field and press <Enter>, (5) pan/zoom to the next feature, and (6) repeat steps 4-5 until all features have been attributed (fig. 1). This list of actions becomes the basis for the necessary functions of the script and helps define the keywords for searching for the code snippets that will be needed to create the script, which will be discussed in the next section.

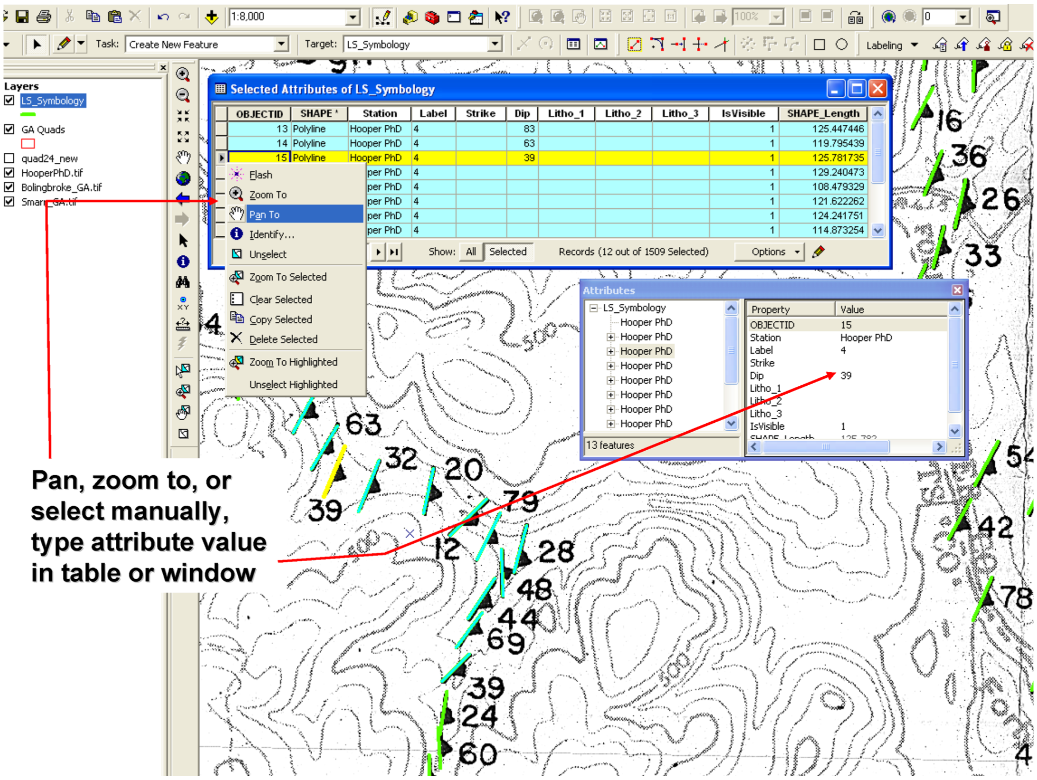

Figure 1. Screenshot of ArcMap displaying an excerpt of a geologic map scanned from a Mylar sheet. The layer attribute table and the Editor feature attribute window are open. Selected features can have attribute values added manually through either interface. The "Attribute Features" script seeks to automate this laborious data entry process.

Table 1. Matrix for comparing time estimates for a task in ArcMap to help determine the benefit from development of an automation. sec, second; hr, hour.

	Time per feature (sec)	Features to process on one map (avg)		Time to process 1 map (hrs)	Total Time (inc. 8 hrs dev.)	Total Time for 10 maps (hrs)
By hand (no auto)	25	1500	25s x 1500 = 37500s / 3600s/hr =	10.42	n/a	104.17
Est. w/ auto (50% of "by hand")	12.5	1500	12.5s x 1500 = 18750s / 3600s/hr =	5.21	13.21	60.08
Actual (timed w/ auto)	4.5	1500	4.5s x 1500 = 6750s / 3600s/hr =	1.88	9.88	26.75
			Time needed to develop basic automation =		8	hrs

There will undoubtedly be a need to justify the time spent on creating a customization. To do so, create a simple matrix similar to that in table 1 as an aid in presenting your case to supervisors or management. Taking the example scenario outlined in the previous paragraph, I attributed a few dozen features using the "by hand" method in order to get a sense of how much time it would take to perform the attribution manually (row 1). In my experience with automating processes, the time savings can be from 50 to 90 percent depending on the function. A safe figure to use when estimating the time savings is probably 50 percent (row 2). This should provide a reasonable estimate of the time savings over many iterations of a common task that you wish to automate. I also calculated the actual savings after the script was completed and used to attribute all the features on a map (row 3). In this particular scenario, the actual time savings per feature were quite substantial, around 80 percent compared to the manual method, not counting the time taken to put the code together. Considering the time taken to create the basic version of the script (about one working day), the savings from converting only one map of this type does not appear significant since the time would be almost equal. However, utilizing this script on just 2 maps would probably justify the time spent on the automation, and the time saved on 10 maps would be even more significant. Also, it is important to remember that, if you are a newcomer to programming of any kind, taking a couple of hours every other day over the course of a few weeks to familiarize yourself with some basics of VBA will really help to speed script creation.

Script Setup, Searching and Assembling Code

The best resource for learning to code is the ArcGIS Desktop Help (*http://webhelp.esri.com*). Under the topic "Writing macros using VBA," the section entitled "Sample VBA code" has 10 scripting samples that are designed to help the novice user understand some of the important scripting tasks, including adding layers to a map and calculating values for a field in an attribute table. These samples have detailed instructions on how and where to put the code in the VBE and how to call the script in your ArcMap session. Once you have familiarized yourself with the VBE and code samples, and how they work, you can begin to search for the code samples that you need to complete your automation goal.

After identifying the basic requirements for your script (as outlined in the previous section), begin your coding by searching on the ESRI Developer Network Web site (*http://edn.esri.com*) or the ESRI Support Web site (*http://support.esri.com*) using keywords for the functions you are trying to automate. Code samples that can accomplish these tasks can be found using the example of the semiautomatic attribution of features, searching on keywords such as "select features programmatically," "store attribute," "zoom to feature," and "loop through selected features." It is often the case that the code samples returned for such searches are much more complex than necessary. Sometimes the code will have to be read through to extract only the parts that pertain to the task at hand. This process can be time consuming, but as you become more familiar with the syntax and form of the code, looking for the sections you need becomes much easier. Also, an additional advantage to many of the samples available from ESRI Developer Network in particular, is that the code is well described with internal comments that explain what the code does, section by section. Remember, you don't have to completely understand why a piece of code works as long as you can organize the code sections logically to execute and obtain a suitable outcome. The key is to use existing scripts and modify them. This is an excellent way to learn VBA (or any programming language): take code that is already written and play with it, modify it, and learn how it works through trial-and-error testing.

Testing Scripts: Tips and Tricks

Once pieces of code have been found, assemble them in the VBE and begin the process of testing and debugging the code. It is important to note that testing should never be done on anything but sample datasets or copies of datasets. Until you are confident that your code is stable and will work properly, anything could happen, including lock-ups, crashes, or corruption to datasets, so save your work often. Also, never run multiple sessions of ArcMap when scripting with VBA. This will prevent problems with the Normal.mxt (the default template initialized each time ArcMap starts), which stores code and user form modules.

In most cases, running code that contains errors (which is inevitable) will cause the VBE to stop execution of the code and present the user with an error message. The error message offers the option to view the offending line and help to fix the problem. There may be cases where the error is not a syntax issue per se, but one of unexpected behavior or poor performance, as with a non-exiting loop or use of an improper cursor. In a case like this, the user can stop code execution at any time by pressing Ctrl + Pause/Break. Sometimes, errors are not identified directly by the line on which they occur. The best way to trap errors of an ambiguous nature may be to execute the code line by line or to establish breakpoints in the code to step through section by section. Alternatively, the Immediate Window in the VBE and (or) pop-up message boxes display variables being used as the code executes or signal the completion of a section of code:

```
' Give a value to an object:
Dim sValue As String
sValue = "Hello world!"
' Display the value to the user using
message box:
MsgBox "The value of sValue is: " & sValue
' Display the value to the user using the
Immediate Window:
Debug.Print "The value of sValue is: " &
sValue
```

This method can help identify problems by showing when a variable that is needed returns a null value ("") or the word "Nothing".

Once code has been tested and seems to work well within your specifications, save the working code to a text file or export the code module from the VBE to a file. As code becomes more complex, errors can be introduced by the addition of, or changes to, code that cannot be undone, and reversion may be necessary. *Never* delete lines of code unless you are sure they are not necessary. Instead, use comments to "hide" code from being executed. Comments are simply a single quote character " ' " that precedes any part of a line of code and can be used to make the VBE ignore a line:

```
' Execute this line:
Set pDataStats = New esriGeoDatabase.
DataStatistics 'after comment
' Not this one:
'Set pDataStats = esriGeoDatabase.
DataStatistics
```

This can be very helpful in testing different syntax without deleting anything, in case a mistake is made. Only at the end of a project do I remove lines as part of the project cleanup and preparation to post the code for public dissemination. Comments can also be used to describe a function or explain the use of a certain object or variable, making code easier to understand and be used by others (fig. 2).

Notice that the code in the VBE window shown in figure 2 is colorized to improve the readability. By default, comments will be green, keywords will be blue, errors will be red, and normal and parameter text will be black. These colors can be changed by the user, but I do not recommend it since these are standard, and many of the code samples from the web and ESRI Developer Network are colored in this way.

Finishing Code: Final Considerations

When your script is complete you can consider adding a few things to make the code more robust and more polished, especially if you are considering posting the code samples to the ESRI Resource Center Code Galleries or ArcScripts. One important feature for all code is the ability to gracefully quit and notify the user when an error occurs. Even if you test your code a thousand times with no errors, distribute the code and someone will surely find a way to make it crash. A simple error handler is not hard to add and makes your code able to deal with errors and exceptions in a more professional way:

```
Public Sub StartGeoMapEditSession_Click()
' Put this line of code after the first
line of the Sub or Function:
On Error GoTo ErrHandler

' MAIN BODY OF CODE GOES HERE

' Just before End Sub or End Function:
Exit Sub ' or "Exit Function"

ErrHandler:
MsgBox "Error Number: " & Err.Number &
vbCr & "Error Source: " & Err.Source
& vbCr & "Error Description: " & Err.
Description & "." & vbCr & vbCr &
"Operation canceled!!", vbCritical,
"ArcMap"

'Now comes End Sub or End Function
End Sub ' or "End Function"
```

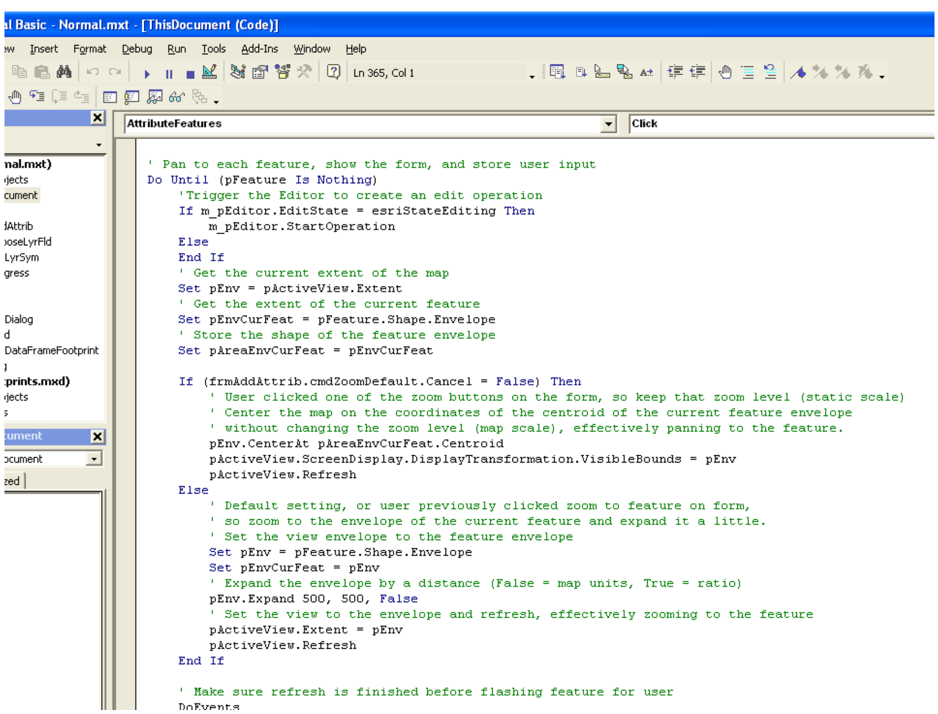

Figure 2. Screenshot of the Visual Basic Editor code window. Notice comments in the code (in green), marked by " ' ", improve the readability of the code and make it easier to understand the functions.

With this code in your script, if there is an error while running the Sub or Function, the operation will be canceled and a message box that identifies the error number—the error source module—and the error description (if applicable) will be displayed.

Another nice feature to add to your code is a comment section at the beginning of the sub or function that identifies who created it, describes what the function does, when/what updates have been made, and so forth:

```
Private Sub CreateDataFrameFootprint_
Click()

' Created by Andrew L. Wunderlich
' September 10, 2007
' Updated:
' December, 2007 - added data frame
rotation
' June, 2008 - fixed scale number problem
' May, 2009 - added densification routine
' ===================================
' This tool converts the data frame
' envelope to a polygon and exports
' it to a shapefile with user-
' specified name and location and
' adds it to the map document.
' The tool also takes into account
' Data Frame rotation, if any, and
' rotates the polygon to match.
' The output shapefile contains three
' fields: the map document name,
' the map scale, and the rotation
' in degrees (counterclockwise).
```

As you work on your own projects and search and retrieve code samples from the Web, you will certainly find other things that you will want to add to your code to make it more robust, user friendly, and functional. Try different things and be creative: a solution to almost any automation goal can be achieved by searching the resources and using the methods outlined here.

Coding Resources

These resources help you create custom code:

Getting started with VBA:

- "Getting started with VBA" in the ArcGIS Desktop Help
http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Getting_started_with_VBA

- "Sample VBA Code" in the ArcGIS Desktop Help
http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Sample_VBA_code

- "Customizing ArcGIS desktop with VBA"
http://resources.esri.com/help/9.3/arcgisdesktop/com/vba_start.htm

- ArcGIS Web Help – general topics
http://webhelp.esri.com

ESRI Developer Network:

- Homepage for scripting with ArcGIS 9.2 (and earlier)
http://edn.esri.com

- Code Exchange – find code samples and documentation
http://edn.esri.com/index.cfm?fa=codeExch.gateway

ESRI Resource Center:

- ArcGIS 9.3 (and later) resources for developers
http://resources.esri.com/arcgisdesktop/index.cfm?fa=forDevelopers

ESRI Support Center and ArcScripts:

- ESRI Support Center – search for help with solutions to automation problems. User can create an ESRI Global Account to post questions, watch threads, and post solutions to others' problems. Highly recommended!
http://support.esri.com

- ArcScripts – homepage for user community script posting and exchange. Code for scripts I presented in my PowerPoint at the DMT '09 meeting, including the Attribute Features script, can be downloaded. Search with keyword "Wunderlich."
http://arcscripts.esri.com

Acknowledgments

Support by Dr. Robert D. Hatcher, Jr., the University of Tennessee Science Alliance Centers of Excellence, and the USGS NCGMP through Grant Number 08HQGR0098 is greatly appreciated.

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ESRI Developer Network, 2009b, How can you customize ArcGIS Desktop?: Getting started developing for ArcGIS Desktop, accessed at *http://edndoc.esri.com/arcobjects/9.2/CPP_VB6_VBA_VCPP_Doc/COM/VBA/what_develop_dtop.htm*

A Desktop Screen Analysis for Wind Farm Siting

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Introduction

A site suitability analysis conducted in a geographic information system (GIS) requires data appropriate for the type, and scale, of analysis being conducted. GIS data that had been created in the public domain, often available at little to no cost to users, is an essential commodity for GIS projects. These data are an ideal fit for projects with small budgets and fast turn-around times. We commonly conduct projects that lack the budget and (or) timeframe to acquire new data. In these situations, free data that are made available to the public through Federal, State, and local government organizations, universities, and other entities can be the only feasible means to complete a project. An example of this was a wind farm screening study conducted by Fugro-William Lettis & Associates, Inc. (FWLA) in 2008. For this study FWLA conducted a site selecting screening analysis for two potential wind farm sites using freely available data. The analysis was conducted knowing that the data used had limitations related to scale and resolution. These limitations were made clear to the client. These data provided FWLA with the ability to conduct a desktop site suitability analysis for both potential wind farm sites.

Methodology

The desktop assessment of site suitability involved the review of available topographic, geologic, and geotechnical properties. The quality of this assessment is often dependent on available data. For the two wind farm sites being studied, our analysis included:

- Site geology assessment
- Soils assessment
- Topography and slope assessment
- Determination of rock rippability
- Calculation of an estimated volume for rock material that would need to be excavated for construction of an access road.

Both sites are located within the State of California but differ significantly in terms of site geology, topographic slope, and access issues.

- Site 1 was situated along the coast of central California. This site was located atop coastal ridges with moderate to steep, vegetated slopes. The site has few bedrock exposures as these ridges are mostly covered with soil. A network of established dirt roads along the ridges would provide access to most of the proposed wind turbine locations.
- Site 2 was located in the Mojave Desert of Southern California. This is a bedrock and alluvium site with steep to very steep slopes in bedrock, and gentle to moderate slopes in alluvium. Unlike Site 1 this area lacks a network of developed roads. To gain access to the proposed wind turbine sites, new roads would need to be constructed. Most new road construction and all proposed wind turbines were located over bedrock of varying lithologies. The only access roads located over alluvium would be those located at the foot and flanks of the mountain.

Data Acquisition

The first step of our desktop analysis was to build the GIS data library. Our data search included sources of topographic, geologic, soil, and aerial imagery. Aside from scanned copies of U.S. Geological Survey (USGS) 1:24,000-scale topographic quadrangle maps that we annotated with preliminary road alignments and wind turbine sites, all data were downloaded from a variety of U.S. Government agency Web sites. These Web sites were designed with well-organized user interfaces and provided relatively easy access to the data.

The digitally scanned copies of USGS 1:24,000-scale topographic quadrangle maps provided by the client proved to be warped by the scanning process. New files were obtained from California's Cal-Atlas Geospatial Clearinghouse (*http://www.atlas.ca.gov/*). Digital Orthophoto Quarter Quadrangles (DOQQs) also were downloaded from the Cal-Atlas site. GIS databases in the Environmental Research Systems Institute's (ESRI) shapefile format, representing mapped soil units, were obtained from the United States Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS), via the Soil Data Mart Web site (*http://soildatamart.nrcs.usda.gov/USDGSM.aspx*). Digital elevation models (DEMs) from the National Elevation Dataset (NED) at a 10-meter resolution were downloaded from the USGS National Map Seamless Server (*http://seamless.usgs.gov/*). Geologic data for Site 1 were downloaded from the San Louis Obispo County's SLO DataFinder page (*http://lib.calpoly.edu/collections/gis/slodatafinder/*). Site 2 was previously mapped by the USGS as part of Miscellaneous Field Studies Map MF-2344 by Howard (2002). The geologic map and associated shapefiles were downloaded from the USGS Publications Warehouse (*http://pubs.usgs.gov/mf/2002/2344/*).

Site Soils Assessment

Processing began with the soil shapefiles, using the USDA Soil Data Viewer (*http://soils.usda.gov/sdv/*). This tool can be downloaded from the USDA and operates as an extension in ArcMap. The tool allows for an end user to easily access the complex database that is associated with each soil map unit shapefile. In this case, the Soil Data Viewer was used to access the concrete and steel corrosion values for soil units exposed at Site 1. Corrosion values are grouped by the USDA into qualitative values of low, medium, and high. These groupings were used to reclassify the soil shapefile, which then was intersected with the wind turbine sites. This analysis was conducted only for Site 1 because of the lack of soil mapping at Site 2.

Rippability Assessment

An assessment of rock rippability was performed for both sites to estimate levels of difficulty to be encountered during the construction of the access road and wind turbine foundations. The original plan for determining rippability was to reference the Caterpillar, Inc., rock rippability charts (Caterpillar, 1995), which requires measured seismic velocities of the underlying bedrock units. Site specific seismic velocity measurements were not available for either site, so velocity values were estimated for each rock type based on velocity charts found in Barton (2006) and Rahn (1996). However, because a measured velocity value was not available, it was determined that a relative rippability chart would be more appropriate. For Site 1, where bedrock conditions are less complex, bedrock types were divided into groups of "less rippable" and "more rippable." An attribute field was added to indicate the level of rippability and the geologic units were attributed appropriately. The "more rippable" units were mostly surficial deposits of Quaternary age, whereas the "less rippable" were Tertiary-age sandstone, shale, claystone, siltstone, and tuff. Site 2 was more geologically complex and was broken into four groups of relative rippability. From most rippable to least rippable the units were (1) alluvium and windblown sand, (2) intrusive dacite, (3) aplite, granite gneiss, breccia, and granite, and (4) tectonic schist and basalt (fig. 1).

DEM data were processed and analyzed to estimate the amount of rock material to be excavated during access road construction. The 10-meter DEM base was also used to create slope maps for access road and wind turbine pad siting analysis. For these studies, higher resolution elevation data such as LiDAR (Light Distance and Ranging) would have been preferred, but the limited project budget and short turn-around time prevented acquiring such data. The next best available data were the 10-meter NED data provided by the USGS. Slope studies at both sites utilized 10-meter DEMs and 1:24,000-scale USGS topographic maps. The DEMs were processed using the ArcGIS 3D Analyst extension to display values of slope as a percentage. These maps symbolized percent slope using 5-percent intervals overlain with the proposed roads, wind turbine sites, and topographic maps. This process quickly revealed sections of roads that needed to be considered for rerouting.

Cut Volume Analysis

Analysis of cut volume proved to be more complicated. We investigated whether ArcGIS had built-in tools that would allow us to analyze a road (line feature) and a DEM to determine an estimate of earth material volume that would need to be removed to create the road, but found that no such tool existed. A process was developed which began by assuming the access road width would be 30 feet, or the approximate width of a single 10-meter DEM cell. To make this process work we also had to assume that all cuts would be made along the slope and at an angle because cuts of different shapes cannot be calculated easily with this method. To begin the process, a line feature representing the access road was intersected with the slope map (by percent) raster. The corresponding raster cells were saved, with slope attributes, as a new file and converted to a shapefile. This process created a network of grid cells measuring 30 feet by 30 feet, with slope values, arranged in the pattern of the access roads. The attribute table of this new shapefile was arranged to calculate an estimated amount of material to be removed for 1:1 and 1:2 cut slopes for each cell. Using the slope determined by the slope map, and knowing the width of the road to be 30 feet, a hypothetical wall height of a 90-degree cut could be determined. These

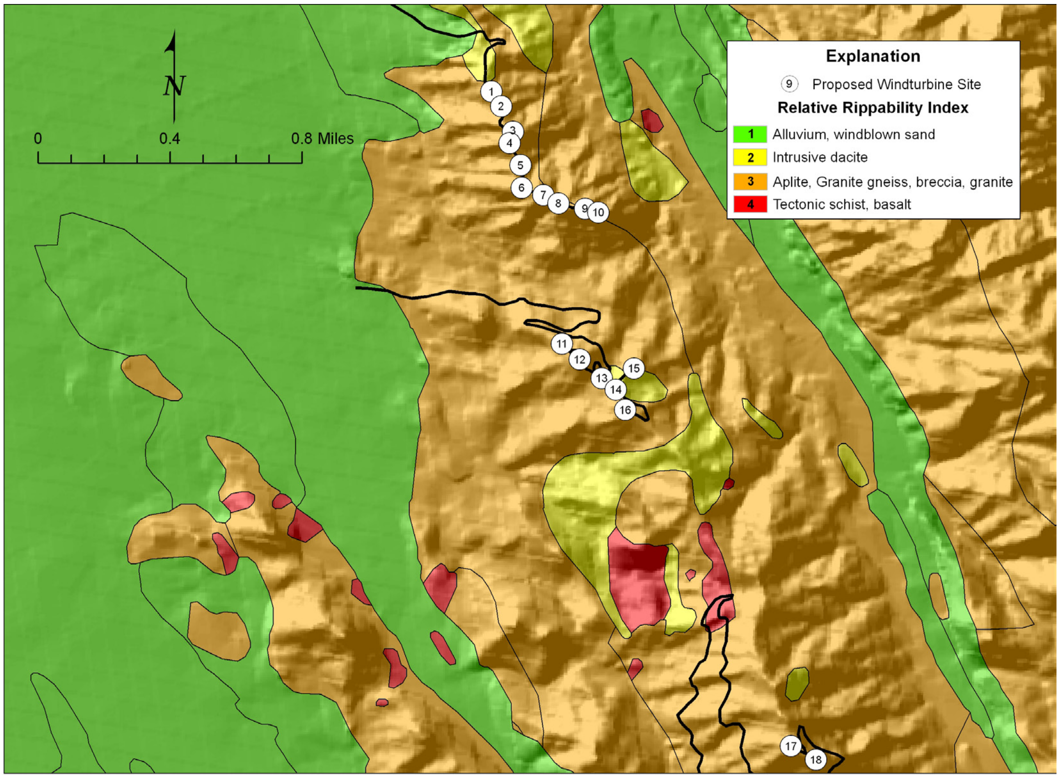

Figure 1. Relative rippability map of Site 2 showing proposed access roads (thick, black lines) and wind turbine sites. Geologic map from Howard (2002).

values were then used in simple trigonometry equations to calculate the volume of material to be removed with 1:1 and 1:2 cuts. This analysis was conducted only at Site 2. At Site 1, existing roads, relatively level approaches, and exposed soil at the ground surface rather than bedrock made it unnecessary to calculate the amount of material to be removed.

Another tool which proved to be very helpful in site analysis and presentation was Google Earth. Shapefiles representing roads, wind turbines, geology, and soil were exported as KML (Keyhole Markup Language) format from ArcGIS and opened within Google Earth. Wind turbine icons were created using Google SketchUp and placed over proposed wind turbine sites (fig. 2). This process aided in the visual evaluation of site road conditions and slope. Three-dimensional screen images were also exported and used to demonstrate site conditions during presentations to the client.

Results

For both sites, conditions were evaluated using ArcGIS, 3D Analyst, and Google Earth. The combination of these software packages allowed us to analyze available data and to address our primary assessment tasks:

- Site geologic conditions were assessed using published geologic maps. These data were combined with published information regarding rippability to created relative rippability assessments for both sites.
- Using USDA soil shapefiles and the Soil Data Viewer, Site 1 was analyzed for corrosive conditions.
- To evaluate slope conditions and proposed access road routes, DEMs and orthophotos were analyzed in ArcMap, and relevant files were imported into Google Earth for enhanced visualization.

In addition to the results listed above, for Site 2 the shapefile representing the gridded road (which was used to calculate cut volumes) was intersected with the rippability index map. Rippability values were spatially joined to the shapefile that represented the road. The attribute table containing relative rippability values, seismic velocity ranges, road segment length, bedrock types, and cut volumes was exported and summed in a spreadsheet. That summary (table 1) allowed the client to easily see the rock units they could expect to encounter during construction activities, the length of road to be constructed over each unit, excavation difficulty compared with other units, and estimated volumes of rock material they would be cutting from the slope. A similar table was created

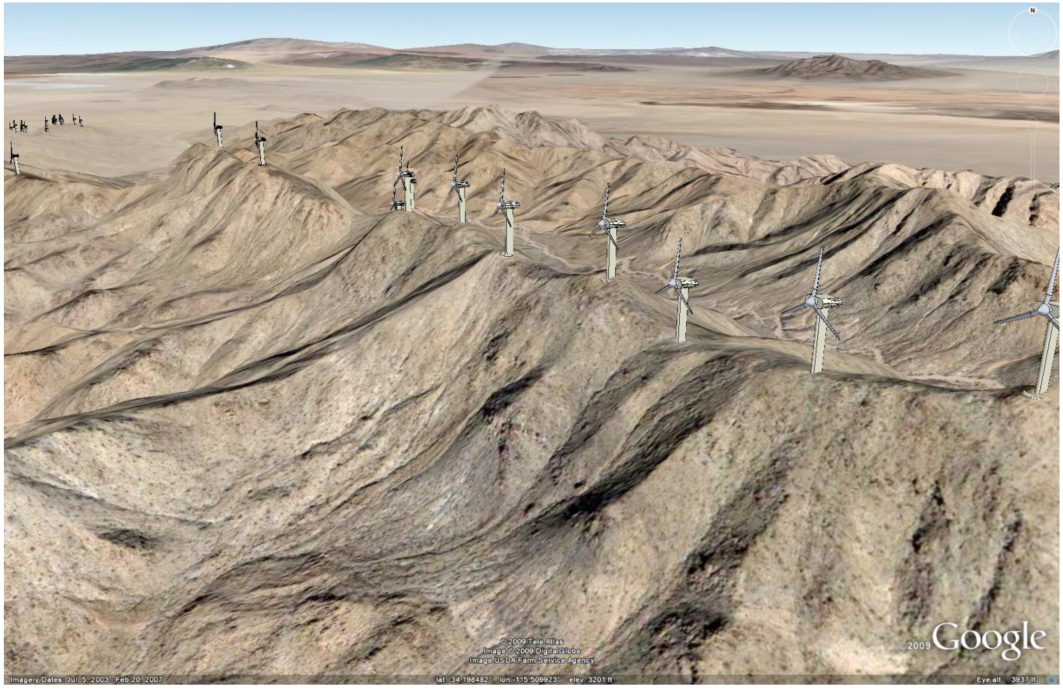

Figure 2. Three-dimensional scene of Site 2 taken from Google Earth with simulated wind turbines created in Google SketchUp.

Table 1. Site 2 relative rippability values and cut volume estimates.

Rock Type	Relative Rippability (1-4)	Velocity Range (kilometers per second)	Road Length (feet)	1:1 Cut Volume (cubic yards)	1:2 Cut Volume (cubic yards)
Tectonic Schist	4	6.0–6.7	18,807.62	235,905.41	139,775.45
Older Alluvium	1	0.5–2.5	4,326.09	9,091.08	8,112.71
Iron Granodiorite Gneiss	3	6.0–6.5	53,608.72	543,735.75	304,268.09
Intrusive Dacite	2	5.4–5.8	2,244.05	69,629.24	31,898.15
Granite Pass Granite	3	6.0–6.2	12,203.39	112,837.99	75,562.03
Danby Lake Granite Gneiss	3	6.0–6.2	31,370.18	489,979.16	264,438.38
Basalt in Iron Mountain	4	5.3–6.5	914.45	5,739.65	4,578.33
			123,474.5	**1,466,918.27**	**807,331.29**

for Site 1 that summarized the same data with cut volume estimates excluded. Excavation for roads was unnecessary at Site 1 because of the existing road network and relatively level approaches to the proposed wind turbine locations.

Limitations

While working with data produced and distributed by many sources, it is important to be aware of the scale of the data. Often the scale will vary, and it is important to convey the limitations of the data to the client. It is also important to clearly indicate the scale in the metadata of any derivative products that are produced. In addition to data scale, it is also important to be aware of any other data limitations. Data gaps, errant values, accuracy issues, and other such problems should be understood and evaluated prior to use. All calculations and analyses were completed with the knowledge that detailed estimates and results would be unobtainable with such coarse data. Work proceeded with the caveat that all estimates on cut volume and slope would be rough estimates.

Summary

This exercise shows how public domain data can easily be used to supply a project with a wide variety of data when time and budget limit the ability to collect custom datasets. Typically, enough public domain data can be gathered to satisfy project requirements. In many cases data will need to be gathered from a variety of locations administered by varying agencies. As a result of different management styles, budgets, and other constraints, one can expect to encounter a variety of user interfaces when attempting to find and download the data. Likewise, inconsistency in data quality, age, metadata detail, and scale can be expected to be encountered. Because these data are distributed by a variety of agencies, significant effort and time may be invested to actually find it. The more experienced a user is with searching the Internet for data, the easier this task becomes. Knowledge of the possible issues listed above can help the user deliver a better product to the client.

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Semiautomated Mapping of Surficial Geologic Deposits from Digital Elevation Models (DEMs) and Hydrologic Network Data

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Introduction

Unconsolidated materials lying above the bedrock are here defined as being surficial materials. These materials often have economic or environmental value. For example, surficial material deposits in alluvial valleys often contain mineral deposits in the form of industrial sands and gravels, metals, or gemstones that have been sorted and concentrated by flowing water. Surficial deposits also often serve as shallow aquifers for groundwater. In addition, alluvial materials deposited in valleys often function as productive agricultural areas because of fertile soils and available water supplies.

Mapping the location, extent, and characteristics of surficial materials has been the focus of several overlapping realms of science. Specifically, surficial materials mapping has been pursued in geology, geography, pedology, and geomorphology. Surficial materials have been classified, mapped, and grouped in a variety of different ways depending on the discipline and purpose of mapping. The mapping of *regolith*, which has been an especially active part of Australian research, has sought to characterize the in situ weathered materials as well as transported materials lying above solid bedrock and is perhaps the most integrative of the surface material disciplines (Scott and Pain, 2008).

In geologic mapping, surficial materials are classified according to their geologic age (for example, to the Neogene Period and Holocene and Pleistocene Epochs), or according to their lithology, or even according to the depositional environment (Maltman, 1998). While the geologic disciplines generally are unconcerned with the organic content of surface materials, surficial geologists often refer to soil maps as a guide or reference to surficial geologic map units (Kite and others, 1995).

When mapping soil associations, soil scientists pay close attention to the landscape and topographic forms, and the organic material present in the soil. The *catena* concept helped to define the understanding that soil map units were inherently linked to topographic processes (Milne, 1935). Soil science is concerned with the underlying geologic materials only to the extent that parent material is one of several soil forming factors; however, geologic maps are an important data source used in the compiling and understanding of soil associations.

Gellert (1972) recognized geomorphologic mapping as a subdiscipline of many related fields of science that are primarily concerned with deriving relief and surface landforms, but also incorporate the qualitative and quantitative observation of the forms as well as the processes which have developed the form. This definition helped to formalize efforts in geomorphological mapping but still failed to unify the methods or purpose of the many different fields contributing to the discipline.

So, the history and tradition of surficial materials mapping has led to differing approaches and to subjectivity in mapping and interpretation. Regardless of discipline, the traditional approach to mapping surficial materials would be field based, but this practice is expensive, and remote field locations pose logistical challenges to effective and efficient mapping. Many disciplines already rely on topographic maps, aerial photographs, and interpretation by professionals to map surficial deposits, yet these interpretations result in highly subjective interpretation and are not easily repeatable methodologies. The lack of repeatability limits the applicability of individual studies over larger areas and often prevents the transfer of a methodology from one field area to another field area where a different terrain may be encountered. Subjectivity in classification and the cost of field mapping require that we develop quantitative and easily replicable scientific methods to map and characterize surficial materials. One way of developing a quantitative approach to surficial material mapping is through geographic information systems (GIS) and digital elevation modeling techniques.

Automated Mapping Review

Automated mapping techniques are based on numerical data, are repeatable, and are quantitatively based. Also, the process is typically implemented in a GIS environment where the results are easily integrated with other datasets and can be iteratively edited and processed with other GIS layers (Longley and others, 2005). The mathematical or morphological definition of particular landforms remains problematic, as semantic definitions vary among the disciplines and no defined standards exist for deriving a landform from an elevation model. This has led to revision and adaptations of models across disciplines and is still an active area of research (Dehn and others, 2001).

The various surficial material disciplines have all contributed studies and research that utilize GIS, remote sensing, and elevation modeling techniques to automate or improve mapping techniques. There has been a broad range of work undertaken to apply different classification techniques, technology, satellite sensors, and models to map surficial materials within each of the related disciplines but often little coordination or sharing of methods across discipline lines.

Geomorphometry or quantitative geomorphology has experienced a resurgence in the form of digital elevation modeling and digital terrain modeling, due to the improved computing power of personal computers, GIS software, and the wide availability of digital elevation models (DEMs) (Pike, 2000). Pike (2000) provides a review of many of the geomorphometric studies completed in soil-landscape relations, landslide hazards, dune mapping, landscape ecology, and other fields. Several studies attempting to map alluvial soils, alluvial plains, and valley bottom settings have been undertaken within several individual disciplines and using different methodologies.

Landform Classification

Hammond (1954, 1964) classified landforms using local relief as the primary means of examining landforms at continental and regional scales. Dikau (1989) extended this methodology, classifying landforms by relief units consisting of slope, local relief, and profile type, to further define forms and facets of the landform. Subsequently, Dikau and others (1991) tested this classification using a digital elevation dataset in a study in New Mexico, thereby automating Hammond's process and recognizing that with available DEMs, countries or large regions could easily be classified through this system.

Wood (1996) used slope, planform curvature, and profile curvature to delineate the morphology of geomorphic signatures into six classes: ridge, channel, plane, peak, pass, and pit. Further analysis showed that geomorphologic units are made up of collections of those morphometric forms and that those forms indicate geomorphic processes at work within the landform classes (Bolongaro-Crevenna and others, 2005).

Williams and others (2000) developed an integrated DEM and vector-based geometric approach to delineating valley bottoms. This study was based on the assumption that valley bottom settings could be distinguished by change in rate of slope from valley bottom to hillslope along the river course. This was a computationally intense process of automatically deriving cross-section statistics along a vector hydrographic network.

Prima and others (2006) used a 50-meter (m) resolution DEM and classified mountains, hills, volcanoes, alluvial plains, and alluvial fans using multidirection slope calculations from a neighborhood of elevation cells and a function of topographic openness which used a line-of-sight principle to determine if a neighborhood of cells is enclosed or open. This work used supervised classification techniques and produced good results for the geomorphology of volcanic mountain ranges in northern Honshu Island, Japan.

An object-oriented classification of landforms and processes associated with mountainous geomorphology realized a high degree of correlation between previously mapped geomorphic units and those predicted using a high-resolution digital terrain model (DTM) derived from Lidar (van Asselen and Seijmonsbergen, 2006). The derived classes included fluvial terraces and alluvial fans as well as shallow and deeply incised channels.

Soil-Landscape Research

Soil-landscape studies have been productive in the use and application of geomorphometric techniques to assess and map the hydromorphic zones and to delineate alluvial soils. McBratney and others (2003) provided a thorough summary and review of the various methods and approaches to digital soil mapping in a GIS environment as well as discussion of the GIS datasets used in the different methods. Park and others (2001) proposed a process-based methodology called the Terrain Characterization Index (TCI) to map the extent of nine soil landscape units in glaciated Wisconsin. Penizek and Boruvka (2008) evaluated three different methodologies for the delineation of alluvial soils from a DEM; the TCI method (originally proposed by Park and others, 2001), the Compound Topographic Index (CTI), and a method using drainage area and height above watercourse. They compared the predicted alluvial soil layers to those on a soil map. Their results indicated that the CTI method underpredicts alluvial soil extent by 43 percent; Park's method underestimated alluvial soil extent by 24.5 percent; and the drainage area and height above watercourse method underestimated soil extent by only 22 percent.

Mourier and others (2008) used the CTI method coupled with the stream-ordering technique proposed by Strahler (1964) to map hydromorphic soil zones in a river catchment in western France. Their findings showed that CTI was a reliable predictor of waterlogged soils in stream orders 1 through 3, but CTI was a less reliable predictor in higher order streams. This was particularly true for orders 6 and 7, owing to the wider and flatter valley floor topography.

Research Goal

The goal of this research is to test two complementary digital terrain-processing techniques for mapping fluvial geomorphology and surficial geologic map units. The study relies on DEM processing and compares the results to two study areas where recent surficial geologic mapping has been completed.

Methodology

Study Areas

Two separate study areas and control datasets were used in this study. The first is the 1:24,000-scale U.S. Geological Survey (USGS) Stanardsville quadrangle in Virginia. Bedrock and surficial geology of the Stanardsville quadrangle was mapped by Southworth and others (2009). Previous surficial mapping of the quadrangle was completed by Eaton and others (2001). Geologic map units representing alluvium, terraces, and debris flows are mapped in each dataset. Both of these maps are also available as digital geologic map databases in the form of ArcInfo layers and shapefiles.

The second study area chosen for this project was the Big Spring quadrangle in Missouri. The geology of the Big Spring quadrangle was mapped by Weary and McDowell (2006) and includes alluvium and terrace deposits mapped along the Current River and its tributaries running from northwest to southeast throughout the study area.

The alluvium mapped in each of the study areas consists of gravel, sand, and clay lying along the bed and active floodplain of the stream valleys. Terrace deposits consist of larger materials from cobble to sand-sized particles deposited on relatively flat areas flanking but above the seasonal floodplain (Weary and McDowell, 2006).

Elevation Source Data

One-third arc-second elevation models for this study were downloaded from the USGS Seamless data server (*http://seamless.usgs.gov*). Each DEM has a nominal horizontal resolution of 10 m and an estimated vertical resolution of ± 7 m. The National Elevation Dataset (NED) DEM data are gridded elevation values interpolated from the original topographic map contour data. The original contour data for the Stanardsville quadrangle was 40 feet (ft) and the contour interval for the Big Spring quadrangle was 20 ft. Each DEM was downloaded in its native unprojected geographic coordinate system and reprojected into a UTM projection. Each NED dataset was then clipped to the 1:24,000-scale USGS quadrangle boundaries.

DEM Data Preprocessing

NED data were reprocessed in order to prepare each dataset for the path distance function and relative relief modeling. First, each DEM was “filled” to remove pits and spikes in the data and to enforce hydrological flow across the surface of the DEM. Next, flow direction was calculated and a flow accumulation analysis was performed. Flow direction determines the cardinal direction of flow from an upslope cell to its downslope cell neighbor. Flow accumulation then determines the number of upslope cells which drain or flow into each subsequent cell. The flow accumulation result grid is classed into categories. All cells with an accumulation value of 1,000 or greater are classified as a flowpath or “synthetic stream line.” The value of 1,000 cells is based in part on the work of Tarboton and others (1991), but has been adjusted to account for a higher resolution DEM (10 m) as compared to the 30-m DEMs used in the earlier study. Cells with a value of less than 1,000 were classed as ‘NoData’. Strahler stream orders were calculated for each flow path segment (fig. 1). Strahler stream orders 1 and 2 were removed, leaving only orders three and higher for the alluvial modeling. Watersheds were derived for all flow paths in the study areas based on the remaining Strahler streams. Finally, the minimum elevation of the watershed for each flow path was determined by intersecting the watersheds layer with the DEM data and finding the minimum value per watershed area.

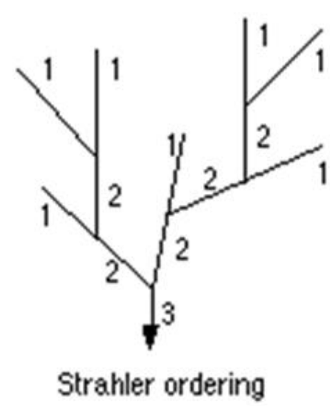

Figure 1. Diagram showing Strahler (1964) stream ordering scheme for orders 1, 2, and 3.

In this study, a path-distance function and relative relief model were used in combination to model the likelihood that fluvial surficial materials were deposited in a given area. The path-distance method presented here calculates the likelihood of alluvial material deposition in proximity to hydrological flowpaths. The flowpaths were each attributed with the Strahler stream order for the model. Based on previous studies in reviewed literature, a determination was made to only calculate alluvial material deposition in Strahler streams with an order of 3 or higher. The following formula is the simple description of the path-distance calculation:

Path-distance = Surface_distance * Cost Raster

Path-Distance Function

Path-distance GIS modeling is a type of cost-distance operation in GIS. Cost-distance operations model the "cost" of movement or travel from a source grid cell in a raster dataset to all other cells in the raster dataset. The cost is determined by both the distance from the source to the other grid cells as well as a numerical "cost" value modeled by a cost-raster layer. Cost rasters numerically model a variety of phenomenon such as the flammability of wildfire fuels, the likelihood of soil erosion or deposition, or the vehicular cost of overland travel or any other type of movement. The cost-raster layers may be numerically stored in a particular type of cost unit such as the financial cost in dollars, or it may be dimensionless and represented as a relative expression of the cost of travel through cells in the raster layer. For this study, the calculated slope of the elevation surface was used as the cost raster (see fig. 2).

Path-distance modeling in GIS extends the cost-distance model to include the complexity of traveling over a surface rather than the more simple Euclidean distance from cell to cell. Typical surfaces used in path-distance modeling are elevation surfaces that represent the terrain of the land surface. Movement over an elevation model surface is a more realistic metric to determine the true distance traveled and its cost. Travel from point A to point B over a flat surface modeled simply as a plane will yield one distance. However, based on the Pythagorean Theorem, travel from point A to point B over a series of hills and valleys modeled by a surface raster grid yields the true distance of traveling over the surface (fig. 3). Figure 4 shows a progression of the simulated raster surface for this study with the path-distance calculated for each cell using the slope values as the cost raster.

Relative Relief Model

The second part of the alluvial deposition model is a relative relief model. Relief is the difference between the highest elevation in a given area and the lowest elevation in the same area (fig. 5). Measures of relief are useful in geomorphometric modeling because they can help to show the complexity and patterns of elevation variation. One problem with using typical relief measures is that they compare elevation values to other elevation values within an analysis window. This is a drawback when the goal of geomorphic modeling is to determine the topographic position of one grid cell to other features, such as base level of a river or the elevation of a ridge upslope of the cell. These features very often will be located outside of the local analysis window and so are not readily compared. Therefore, a different approach needs to be taken to model the relationship of the topographic relief to cells in the grid.

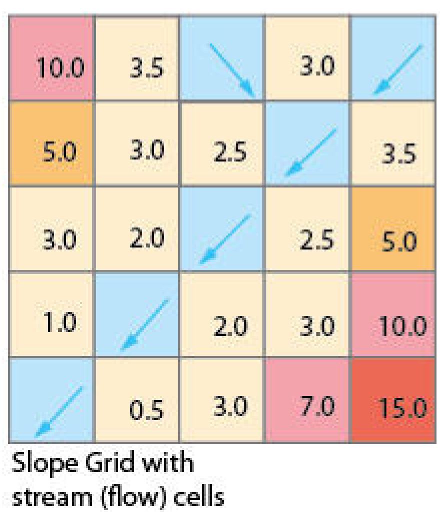

Figure 2. Diagram of simulated raster showing percent slope values derived from DEM and hydrological flow path cells (in blue) with arrows indicating downstream flow direction.

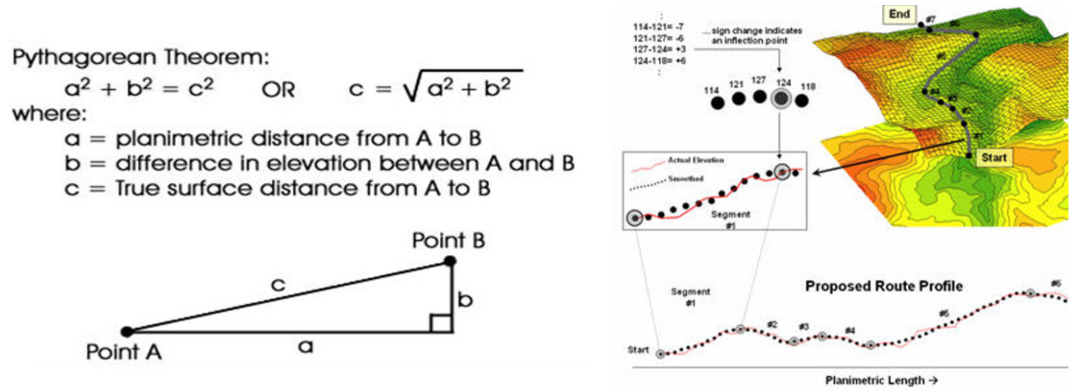

Figure 3. Diagram showing the Pythagorean Theorem (at left) and its implementation in the Path Distance GIS operation on a raster elevation surface (at right).

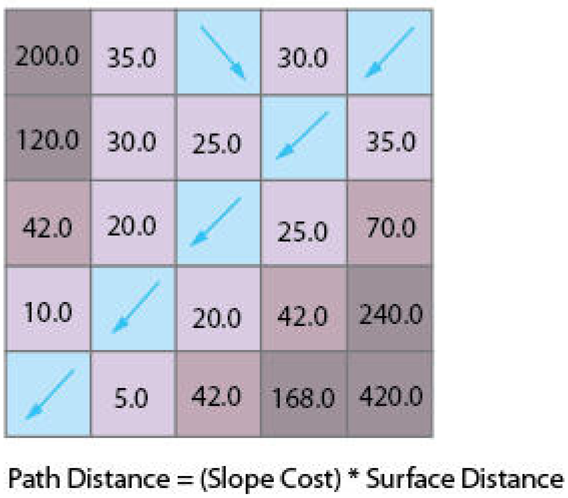

Figure 4. Simulated raster showing the values of grid cells for the path-distance calculation.

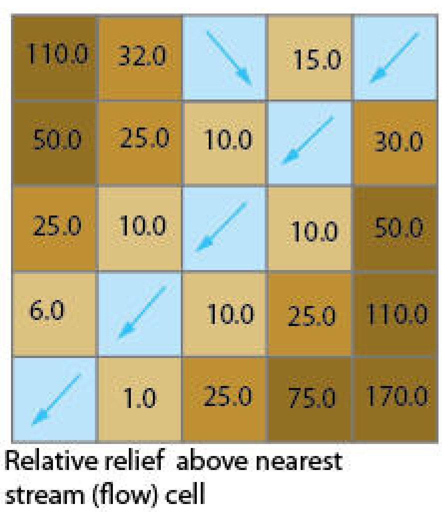

Figure 5. Simulated raster showing the values of grid cells for the relative-relief calculation.

To modify this measure, elevation values were compared to the minimum elevation of the closest flowpath (or stream) grid cell. This measures the relative relief of every cell in the dataset to the minimum value in its local watershed or basin, or to the local baseflow elevation. The benefit of this method is that elevation differences are related to a local, common elevation of the hydrologic network, and thus comparisons can be made more easily from one stream reach to another. This is of particular importance when measuring and comparing alluvial landforms. Figure 5 shows the calculated values for the relative relief parameter for the simulated raster.

In this study, a slope grid is used as the cost raster. Addition modifiers for the relative erosivity of the geologic parent material can be added to this model as well but have been omitted for simplicity. For this study, a uniform erosivity is modeled for parent material layers.

Combination

Once the path-distance model and the relative relief model have been calculated, each resultant dataset was classified into the categories shown in table 1.

Table 1. Classification values from path-distance and relative-relief models for overall alluvial deposition model results.

Path-Distance Model Reclass Values	
0	Stream Channel
0 - 15	Al 1
15 - 50	Al 2
50 - 100	Al 3
100 +	NoData
Relative-Relief Model Reclass Values	
0 - 5	Alluvium
5 - 15	Qt 1 (Terrace)
15 -25	Qt 2 (High Terrace)
25 +	NoData

After each dataset is classified, the two datasets are combined to yield the final alluvial deposition model (fig. 6). The classified results and subsequent combination allow for some interpretation by the analyst as to the values, class widths, and the resultant surficial geologic map units represented by the numerical modeling.

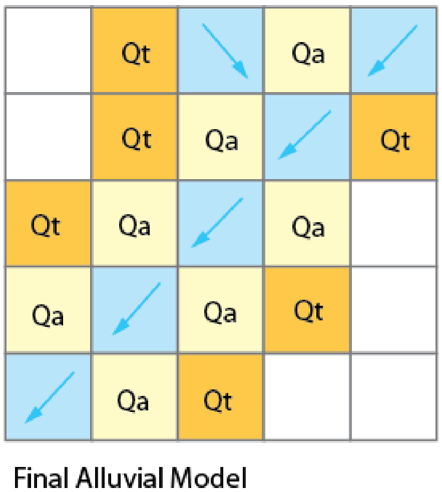

Figure 6. Final results of the path-distance and relative-relief models shown for the simulated raster model, which now represent alluvium and terrace deposits.

Results

Stanardsville

Figure 7 shows the spatial results of the alluvial landform modeling with the mapped units from Southworth and others (2009). Visually, the results appear to be similar, showing a general trend of alluvial materials mapped and predicted in the major river and stream valleys. The alluvial landform modeling results predicted more alluvial map units than what were actually mapped by Southworth. In particular, more alluvium or alluvial terrace deposits were predicted in several of the smaller tributaries.

Statistical correlation coefficient results for both study areas are presented in table 2. The statistical results show that the mapped and the modeled Qa correlate over 38.7 percent of the area. However, when Qa and Qt units are grouped together, the alluvial model showed a correlation of 64.7 percent.

Big Spring

The results for the Big Spring quadrangle show a visual similarity between the alluvial landform model and the mapped surficial geologic units (fig. 8). The alluvial model appears to have predicted more alluvial and terrace material accumulation in several very small streams and tributaries than was previously mapped, yet there is a strong correlation overall between the amounts of material mapped by the alluvial landform model and the amounts mapped by Weary and McDowell (2006).

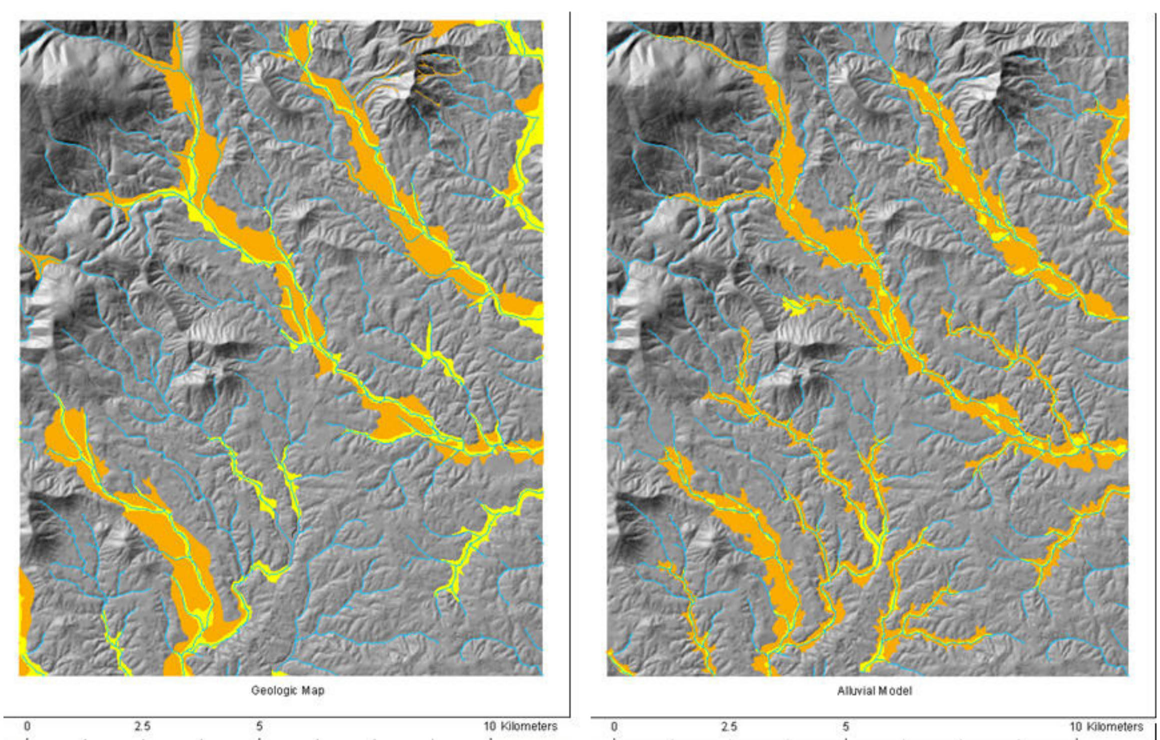

Figure 7. Graphical results of the geologic map (left) and the alluvial deposition model (right) for the Stanardsville quadrangle.

Table 2. Results showing correlations of the mapped and modeled alluvium and terrace deposits, for the Stanardsville and the Big Spring quadrangles.

Study Area	Dataset 1	Dataset 2	Correlation
Stanardsville			
	Mapped Qa	Modeled Qa	38.70%
	Mapped Qa and Qt	Modeled Qa and Qt	64.70%
Big Spring			
	Mapped Qa	Modeled Qa	48.50%
	Mapped Qa and Qt	Modeled Qa and Qt	83.10%

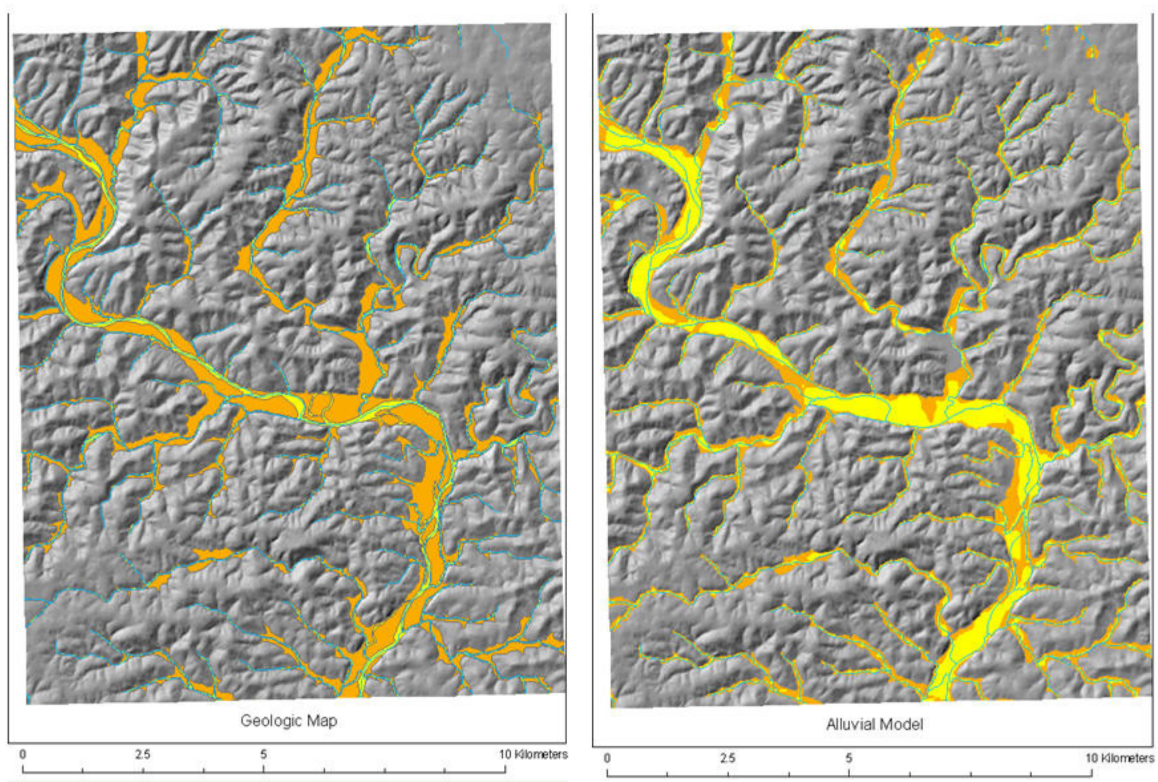

Figure 8. Graphical results of the geologic map (left) and the alluvial deposition model (right) for the Big Spring quadrangle.

The spatial correlation results show that the mapped and modeled Qa units correlate 48.5 percent of the time. When Qa and Qt units are grouped and treated singularly as alluvial materials, the correlation between mapped and modeled results increased to 83.1 percent (Table 2).

Discussion

The results show a cartographic similarity in mapped and modeled alluvium and terrace deposits in both study areas. Overall, there is a general trend of agreement in the determination of alluvial material deposition in proximity to rivers and streams between the terrain modeling approach and the geologic map control data. The difficulty in comparing results lies in the subjectivity of mapping and classifying surficial materials as either alluvium or terrace deposits. Different geologists may choose to classify the units stratigraphically, lithologically, or by depositional environment. Therefore, it may be better to seek a more comprehensive surficial control dataset by which to compare modeled results.

The terrain modeling results show that in both study areas, determining the difference between mapped alluvium and alluvial terrace deposits is difficult. However, when Qa and Qt are combined and viewed as a single alluvial material deposit, the correlation improves significantly. This shows that the alluvial model presented here is an accurate predictor of the deposition of alluvium and terrace deposits. One limiting factor may be the vertical resolution of the DEM data. Since alluvial terrace deposits are typically mapped based on their vertical elevation above the current floodplain, obtaining elevation data that are able to discern fine scale differences in elevation is important. In both cases, the vertical resolution of the DEM data used in this study (+/- 7 m) is greater than the 1- or 2-m difference in elevation between the alluvial flat and the terrace deposits. This indicates that higher vertical resolution DEM data may better be able to distinguish between alluvial deposits and the low terrace deposits which lie a few meters in relief above the flats.

Research using the alluvial model presented here, but using higher vertical resolution elevation data, would be a productive avenue for future studies, especially if validation of fieldwork could be done in order to compare modeled results to conventionally prepared geologic maps.

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Mapping and Geographic Information System Exercises for Freshman and Sophomore College Students

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Introduction

The mapping and Geographic Information Systems (GIS) content of Earth Science Department courses at Vincennes University is designed to provide quality field and GIS experience to freshman and sophomore college students through short duration exercises. These exercises have been conducted in the GIS, Physical Geology, and Mineralogy courses at Vincennes University since 2006.

In the GIS course, students are given hands-on experience with specific aspects of GIS through exercises carried out over two to three class periods, and a half-semester group project that involves planning, data processing, analysis, and a poster presentation.

The Physical Geology and Mineralogy courses contain short, focused mapping exercises that

- Teach field mapping concepts in one lecture, lab, or field introduction.
- Familiarize students with local geologic map units, by conducting one or two lectures and (or) a tour in the field.
- Involve efficient, focused field data collection (in other words, 3 hour lab or 5 hour traverse).
- Include GIS days (1-2 lab periods) involving a combination of student initiative and instructor input.
- Train students to use the ArcGIS functions necessary for specific tasks (for example, Adding XY data, and polygon editing).

GIS Course Exercises

The first half of the GIS course at Vincennes University is built around a series of map assignments - each assignment teaching students one or two important GIS concepts. One assignment familiarizes students with how to display layers of GIS data in the ArcMap module of ArcGIS (ESRI, 2009). Another shows students how to incorporate their own GPS data and display them with aerial photographs. A third assignment introduces students to thematic mapping using data provided with ArcGIS software or through IndianaMap (IGS, 2009). Figure 1 is a student thematic map that uses both proportional symbols and choropleth (color gradation) symbologies to display two themes on the same map. The assignment that students find most challenging requires the use of the spatial analyst extension of ArcGIS to perform raster data transformations and calculations. This assignment requires students to manipulate a Digital Elevation Model (DEM) obtained from IndianaMap to find groundwater seep locations in a hilly region of southern Indiana. Figure 2 is a student map resulting from these analyses.

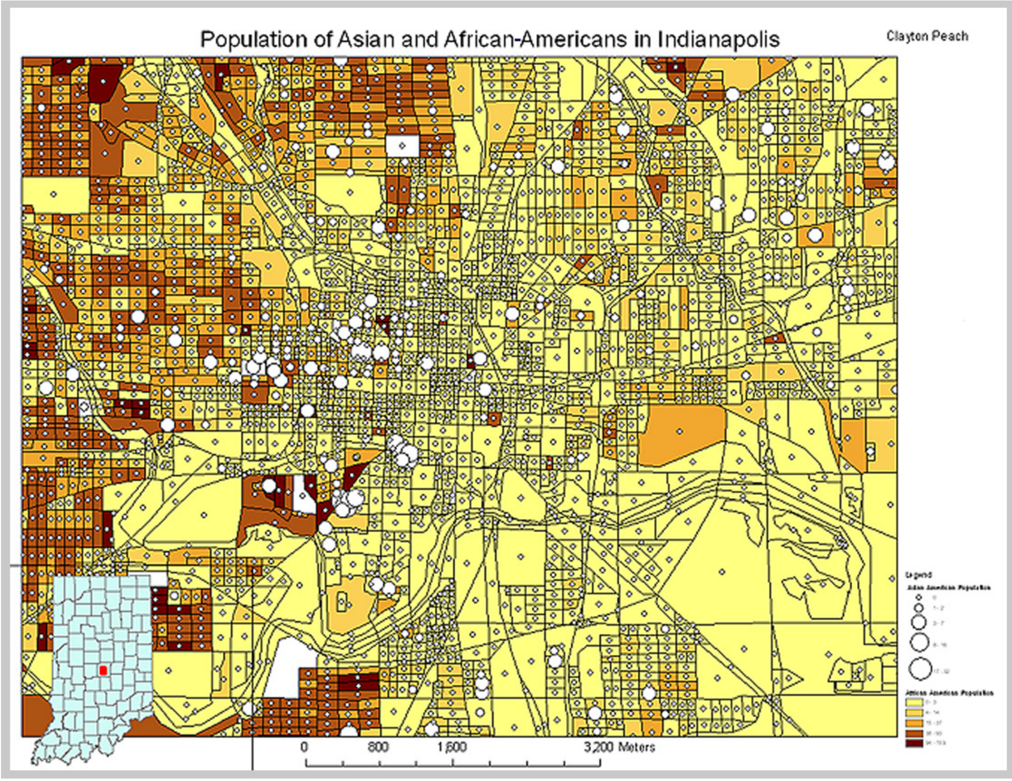

Figure 1. A thematic map showing Asian and African-American populations by Census Block Groups in Indianapolis, IN.

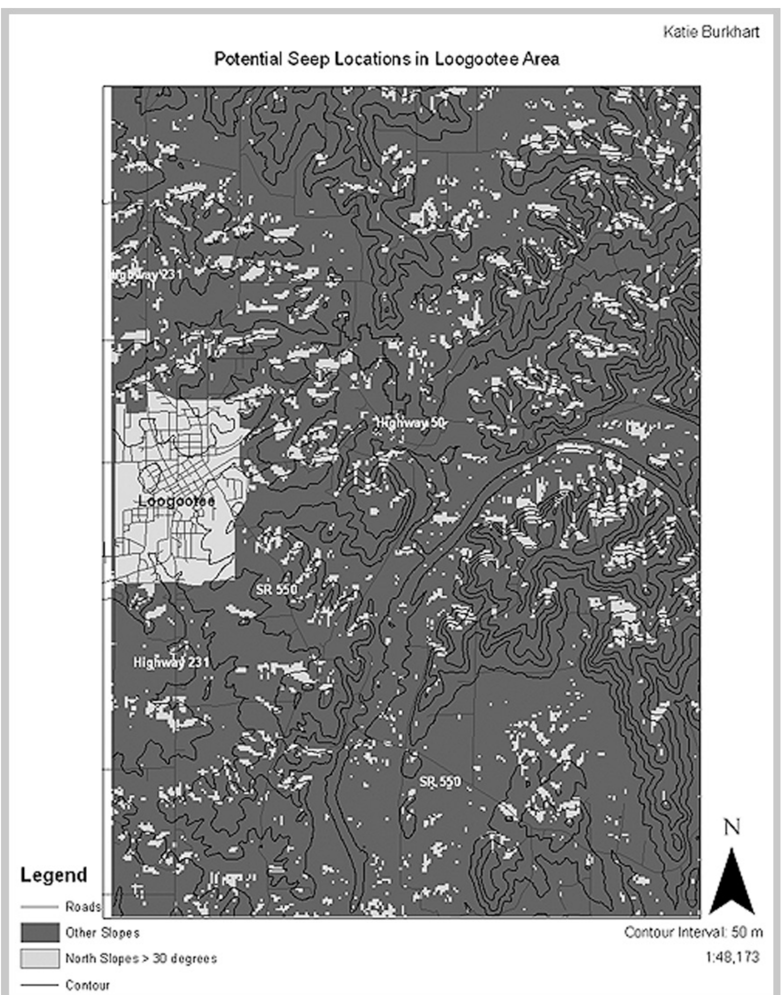

Figure 2. A map showing potential groundwater seep locations in Martin County, IN. The seep locations were determined by slope and aspect analysis of a Digital Elevation Model.

GIS Course Project

The half-semester projects of the GIS course involve planning and carrying out a GIS analysis and presenting the results. The students are required to work in groups and to show initiative in defining the problem they wish to solve as well as planning the GIS analysis steps required to solve it. Some structure is provided to give them smaller steps with deadlines dispersed through half of the project. These steps include a statement of work, flowchart of analysis, draft maps, draft poster, and final poster presentation.

Student projects have covered a number of topics including crime analysis in the City of Chicago, market analysis for siting businesses and health services, determination of the best location for coal mines and wind farms, watershed pollution analyses, forest change analysis, and exploration of connections between geology and forest character.

Land cover change projects typically use the USGS land cover datasets compiled from Landsat satellite data. For Indiana projects, these data are downloaded from IndianaMap (formerly the IN GIS ATLAS) (IGS, 2009). One of the maps from a Southern Indiana forest change analysis is shown in figure 3.

Geographic targeting is one of the GIS principles that is emphasized during the half-semester project. Students are required to use several GIS analysis steps to identify locations that are part of the solution to a relevant societal issue. One group of students combined coal bed thickness data, distances from coal burning power plants, and locations of existing mines in order to determine a location for a new coal mine. The analysis pointed to a region in northern Knox County, IN. Two of the maps produced by these students during their analysis are shown in figures 4 and 5. Coincidentally, a new coal mine has been sited in the region highlighted by the student project.

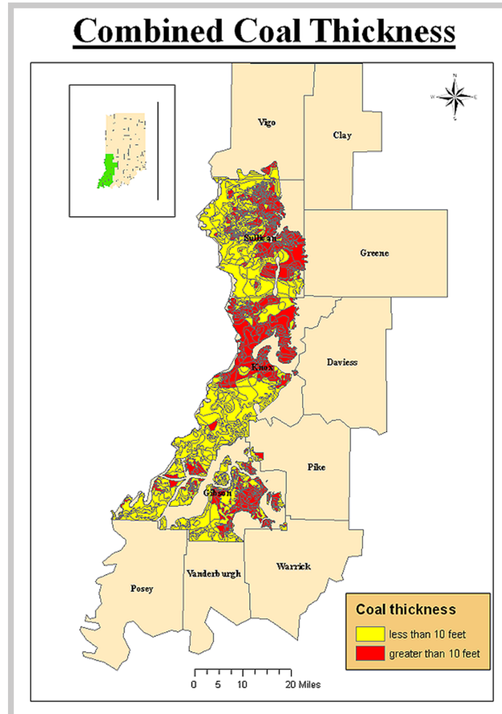

Figure 4. Map showing coal thickness in southwestern Indiana. IndianaMap (IGS, 2009) was the source of the raw data for this analysis.

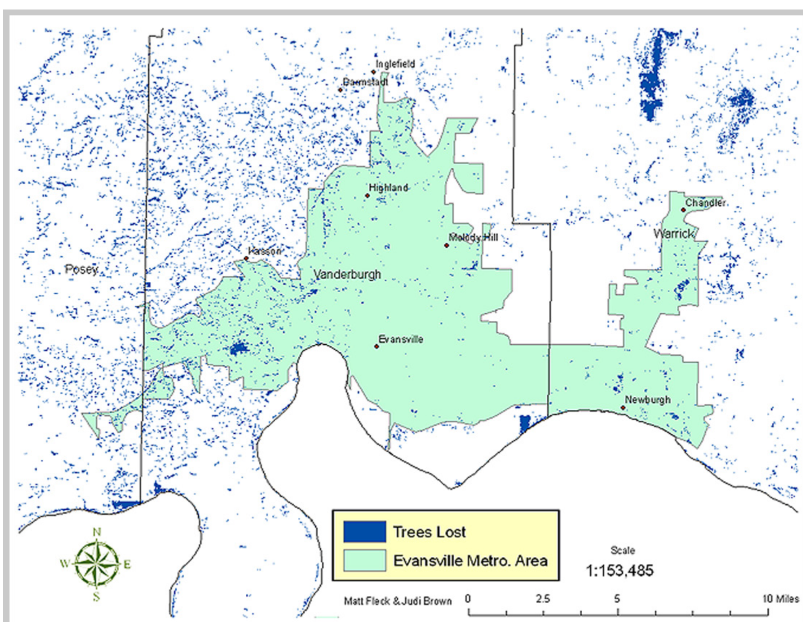

Figure 3. A map showing forest loss in the area of Evansville, IN, determined from raster calculations using satellite data from 2002 and from 1993.

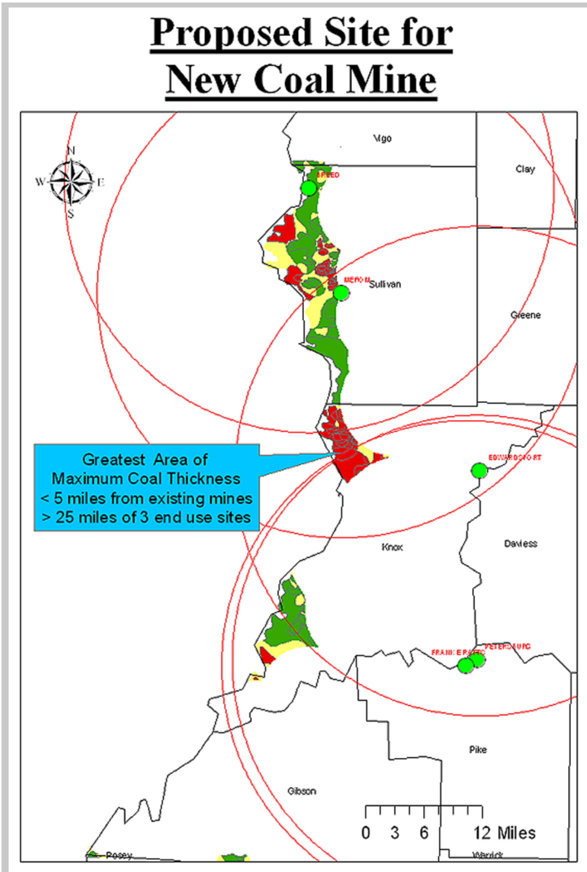

Figure 5. Map showing the preferred location of a new coal mine. IndianaMap (IGS, 2009) was the source of the raw data for this analysis.

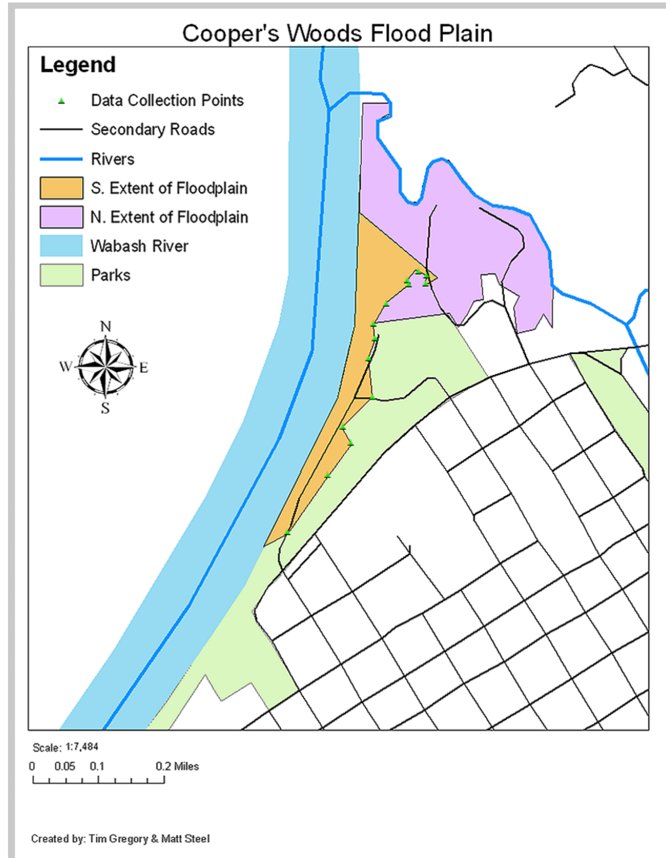

Figure 6. Map of the extent of Wabash floodwaters in late April 2009, produced by Vincennes University students.

Physical Geology Field and GIS Exercises

The Physical Geology laboratory course at Vincennes University involves a mapping exercise in place of four labs at the end of the semester. One to two of these labs involve field work in a local floodplain forest ecosystem along the Wabash River upstream from the Vincennes University campus. In one or two additional lab sessions, the mapping groups (two to four students) bring their field data into ArcMap, draw and edit polygons, and produce a map. Finally, the groups present their finished maps to the class.

Topics for the Physical Geology mapping exercises have included soils, landforms, landuse, stream flow, sedimentary features, and floodwater extents along the Wabash River. Figure 6 is a student map showing the extent of Wabash floodwaters in late April 2009.

Focused Geologic Mapping Exercise

A mapping project conducted with the Mineralogy class in spring 2008 taught students some field fundamentals and GIS functionality through a brief exercise. Students were tasked with mapping a geologic contact between a Precambrian granite and a volcanic rock formation. The field work was conducted in the St. Francois Mountains, MO, and the GIS work done in a follow-up laboratory session at Vincennes University.

During a lecture prior to the field work, geologic maps and literature were consulted. From the geologic maps of Kisvarsanyi and others (1981), the students were introduced to the purpose of their mapping exercise: the verification of the southern contact between the Silver Mine Granite and a volcanic formation.

Other preparations included short demonstrations of how to walk traverses in the field using a compass, how to describe rocks in the field, and how to collect data with hand held GPS receivers.

The exercise involved one long field day. In the morning, students became familiar with the geology of the region and the specific units involved in their mapping problem. In the afternoon, the students formed two groups and conducted traverses across the contact (fig. 7). They followed preplanned routes provided to them on a base map (fig. 8). These preplanned traverses were spaced 0.3 miles apart, allowing the instructor to move between each of the student groups and provide guidance.

Upon returning to the GIS lab, the students used their rock descriptions and GPS data to help them decide where to draw the contact between the Silver Mine Granite and the volcanics. Students used ArcMap to combine their contact lines and base map information.

Figure 7. Photograph of students mapping in the St. Francois Mountains, MO.

Conclusions and Future Improvements

The GIS emphasis in Vincennes University courses strives to provide students with mapping and GIS skills that can be applied to "real world" problems. The focused mapping and GIS exercises seem to convey concepts in an efficient manner. Students have responded well to the structure and content of the exercises. In addition, students have been able to use the familiarity that they gain with the ArcGIS software to their benefit in internships and later coursework.

The instructor of these courses is currently discussing the teaching model and student work with professionals and educators and plans to incorporate their suggestions into future iterations of the courses. One area that has already been identified for improvement involves connecting the coursework with mapping efforts of Federal, State, and local levels of government as well as the private sector.

Acknowledgments

Students of the GIS, Physical Geology, and Mineralogy courses at Vincennes University inspired the hands-on, focused approach to incorporating mapping and GIS into teaching discussed in this paper. The efforts of students have been an important part of the evolution of the coursework, and the writing of this article. These students include: Brian J. Barber, Derek A. Birt, Matthew J. Dixon, Isaac D. Freeman, Joshua L. Graham, Nathan D. Jines, Mark A. Royal, Todd J. Schmidt, Avijit Verma, Matthew R. Wagoner, Jennifer R. Williams, Wesley R. Zellers, Charlotte L. Burnside, Justin A. Diskson, Christopher R. Fogle, Timothy W. Goodwin, Jeremy A. Newhouser, Jarrod S. Perry, Ian P. Wilhite, Sean P. Wood, Kelsey C. Marshall, Wade W. Salmons, Alex P. Walson, Jenny

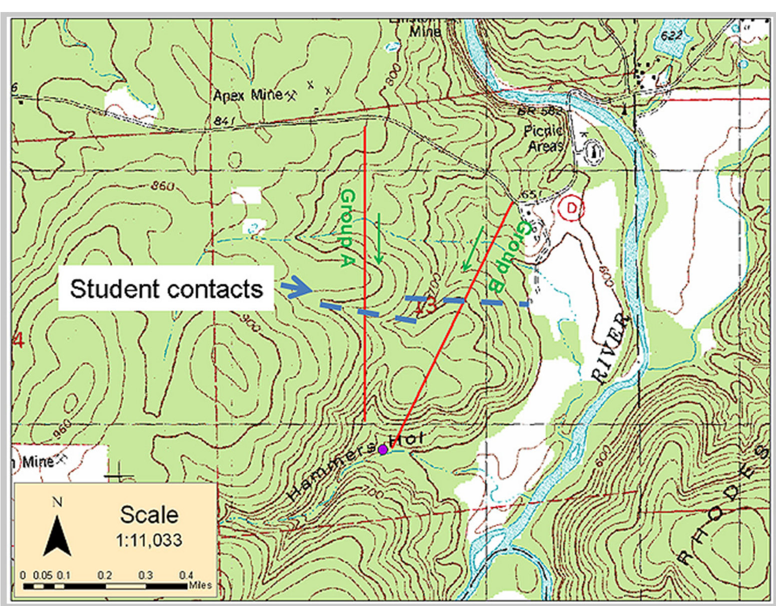

Figure 8. Base map for St. Francois Mountains mapping exercise showing traverses (red lines) and the contact between the Silver Mine Granite and a volcanic formation as drawn by the two student groups.

M. Weeks, Scott E. Whaley, Dathan Wright, Jarrod Albright, John M. Astell, Christopher C. Bledsoe, Joshua A. Galloway, Bryce E. Holtsclaw, Wesley P. Miller, Dustin L. Osborne, Skyler A. Potts, Jason R. Strong, Michael D. Thomas, Christopher R. Allender, Logan M. Croup, Jonathon C. Emly, Tyler J. Thompson, Joseph C. Warren, Amy L. Byrer, Christopher A. Carver, Richard J. Chevalier, Wesley D. Eberhardt, Daniel A. Goedde, Matthew J. Hoffman, Daniel R. Jenny, Robert E. Otten, Alex M. Windes, Erin M. Cash, Adam V. Nease, Stacia K. Pence, and Jessika C. Sanders. Faculty members and administrators at Vincennes University have supported the GIS program, including attending the GIS course poster sessions. Department Chair John Parsons, Dean Richard Shippee, Assistant Professor Curt Coffman, and Adjunct Faculty member Neal Catt have all supported the mapping efforts. The manuscript of this article was reviewed by Shannon N. Doran.

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BGS·SIGMAmobile; the BGS Digital Field Mapping System in Action

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Introduction

The British Geological Survey (BGS) first explored the concept of digital field data collection in the early 1990s, with the conclusion that the mobile computing hardware at that time was not suitable. The development was therefore postponed indefinitely. However a stakeholder review of onshore geological mapping, including the means of collecting data, was undertaken in 2001. The review proposed a major change in survey methodology to include "digital field data capture and desk-top compilation" with "a consistent approach across all terrains and scales of survey" (Walton and Lee, 2001). These review outcomes initiated a major new project to update our mapping systems and workflow; the project was called SIGMA (System for Integrated Geoscience Mapping). One outcome of the new workflow is an implemented digital field data collection system designed and built in BGS; it is called BGS·SIGMAmobile. The system has won awards from both ESRI and the AGI (U.K. Association for Geographic Information). Using examples from current mapping projects, this paper briefly outlines the current capabilities of the BGS system, which is available for free download from the BGS Internet site (as described in more detail below).

System Development

Digital field mapping has been an aim of Geological Survey Organisations (GSOs) for many years. A look through a set of DMT Proceedings from a randomly chosen year (2004) highlights some of the work that has been (and still is being) undertaken in North America. Examples from the 2004 proceedings include Buller (2004) and Haugerud and Thoms (2004) both using Personal Digital Assistants (PDAs) in Canada and the United States, respectively, to collect digital field geological data.

One of the first steps in the development of the BGS SIGMA system was to host an international workshop on digital field data capture at our head office in Nottingham in the U.K. in 2001. Colleagues from mapping agencies and surveys across North America and Europe attended and presented their mapping systems. This was beneficial to all attendees, as the workshop ended with an informal agreement to help each other's developments and cooperate where possible. The presentations from this meeting are available at *http://www.bgs.ac.uk/science/dfdc/home.html*. A similar meeting was held a few years later at the annual meeting of the International Association of Mathematical Geology in Toronto (2005), where the BGS system was presented (Jordan and others, 2005), and another held at the International Geological Congress in Oslo (2008). A session report for the 2008 meeting can also be found at the Web address listed above.

Early incarnations of the BGS system were designed to run on PDAs. A customized version of ESRI ArcPad 6.0.3 (ESRI vendor information is available from *http://www.esri.com/software/arcgis/arcpad/index.html*) served as the front end, whilst a bespoke BGS EVB application containing hard-coded data structure links in a compact database format was used to collect and hold additional relational data (fig. 1). Hierarchical input forms were used to collect various levels of data; index level data were added for each field site and

Figure 1. Screen grabs of the PDA field data capture system, with inset of field use and the complete 'digital toolbox' supplied to geologists.

the "Open Notebook" button gained access to more detailed forms for various mapping modules. The small screen size (approx. 6 x 8 centimeters) was sufficient to display a small map area along with the user's position, which was derived from a Global Positioning System (GPS) grid reference that was served via a Bluetooth GPS device. The field staff were equipped with a 'digital toolbox' containing the PDA, a Bluetooth GPS, a digital camera, and various accessories.

Whilst this was a leap forward from the hardware and software of the 1990s, the screen size was the major limiting factor with the PDA system. It was soon realized that while it was sufficient for point sample collection, it was not suitable for geoscientists working with maps. The screen was too small to visualize enough of the map face to gain a spatial context, and furthermore, annotating the visible area of the maps with lines, polygons, and text proved problematic as much scrolling beyond the current view was required to delineate even the smallest of landscape features. In order to overcome the screen size issue, and to provide additional functionality, BGS developed a system that runs on ruggedised Tablet PCs. We call the Tablet PC system BGS·SIGMAmobile. Internal beta testing began in 2005.

BGS·SIGMAmobile operates in the field on ruggedised Tablet PCs and laptops running XP for Tablet edition. The system will also run on desktop PCs. A heavily customized version of ESRI ArcMap 9.2 (*http://www.esri.com/software/arcgis/*) serves as the front end with relational data held in a customized Microsoft Access 2003 database. Additional functionality is provided by linking modified versions of InkWriter (software that enables handwriting recognition). BGS coding of the SIGMAmobile system is completed using a variety of inputs including VBA and .NET. It should be noted that BGS·SIGMAmobile is one tool in a full workflow (or toolbox) of digital systems and techniques for data compilation, 3D interpretation, data modeling, field data capture, visualization, and publication, all of which are underpinned by approved corporate databases, databanks, and data models (fig. 2).

BGS·SIGMAmobile is an integrated field system that enables the full array of geoscientific data to be recorded using tick boxes, sketches, drop-down lists, tagged free text, and photographs where appropriate. Spatial location and navigation are gained by built-in GPS whilst the stylus enables points, lines, polygons, and comments to be added to the digital map face. As with the PDA system, additional relational information is added using customized forms and a selection of interfaces. The system is modular, with tabs for various themes or domains of geological data such as structural readings, landslide information, auger/section recording, and so on. Furthermore, there are additional tools including the ability to draw sketches, annotate photographs, produce structure contours, and navigate using bearings. All of the data collected in BGS·SIGMAmobile are tagged with a unique user identifier (UUID) enabling the data to be queried in the office and traced through the corporate repositories.

A choice of tools for adding text, lines, and polygons to the map face is provided, ranging from a basic tool that

Figure 2. Representation of some of the BGS systems and techniques for data compilation, 3D interpretation, data modeling, field data capture, visualization, and publication. All of these are underpinned by approved corporate databases, databanks, and data models.

replicates the pencil and paper routine through to tools that enable topologies and attributed lines to be created in the field. Advanced handwriting software is used extensively to provide legible field notes (even on the map face); however, cursive text can still be used for rough notes where appropriate (fig. 3).

Additional data relating to points of interest are recorded via a master form (fig. 4) with buttons that access various modules relating to types of measurements or specialist entry forms. [It should be noted that not all of the modules shown in Figure 4 are available at present on the freely downloadable version.] These data are held in a relational database and may include text, measurements, sketches, photographs, and so on. Index data, such as grid reference, or UUID, are recorded automatically to save time at each location and to ensure that essential data are not omitted. Drop-down menus and tick boxes are used where possible and efficient to ensure that entries conform to accepted standards and that the agreed nomenclature is used, whilst areas for free-form text are also provided to allow flexibility. Novel systems have been developed and employed to ensure that the data recorded are unambiguous; for example, rather than asking a geologist to tick a box to note use of the right-hand rule when recording a structural measurement, we supply a basic compass which is ticked to identify the method used.

As noted above, the field mapping system is one tool in a geological survey workflow. It is therefore vitally important to develop procedures for easy data preparation / compilation prior to fieldwork, followed by straightforward and efficient data transfer / updates back to corporate databases on return from the field. BGS has tools that enable us to view and import the field data in our counterpart office GIS tool (SIGMAdesktop) and corporate databases, but we have also included some shortcuts in BGS·SIGMAmobile which enable data to be extracted from the field relational database into Excel spreadsheets. In addition to this, one of the developments that BGS is currently focusing on is the ability to transfer automatically all of the field data to our corporate databases with one button click, with quality control (QC) on-the-fly. However, because we are collecting more information in the field than many of the databases are designed to hold, it is resulting in some redesign of databases and some inventive data transfer coding.

Before BGS field staff use the equipment on mapping projects, they are provided with in-house training, in addition to the standard ArcGIS courses that we present. The training ensures that each geoscientist is aware of the capabilities of the system, how to apply them to the particular mapping application, how to prepare data and care for the equipment, and how to ensure that any health and safety issues of using computing equipment in the field are addressed. The training course spans two days: the first day covers hardware issues and guides geoscientists through the user interface; the second day is divided into a field trip to practice real-world field mapping at appropriate sites, followed by an afternoon session in the office learning how to extract the data from BGS·SIGMAmobile prior to further manipulation and study. We endeavour to group the training course attendees by their field of expertise so that, for example, overseas mappers are trained together in groups, as are bedrock mappers, landslide

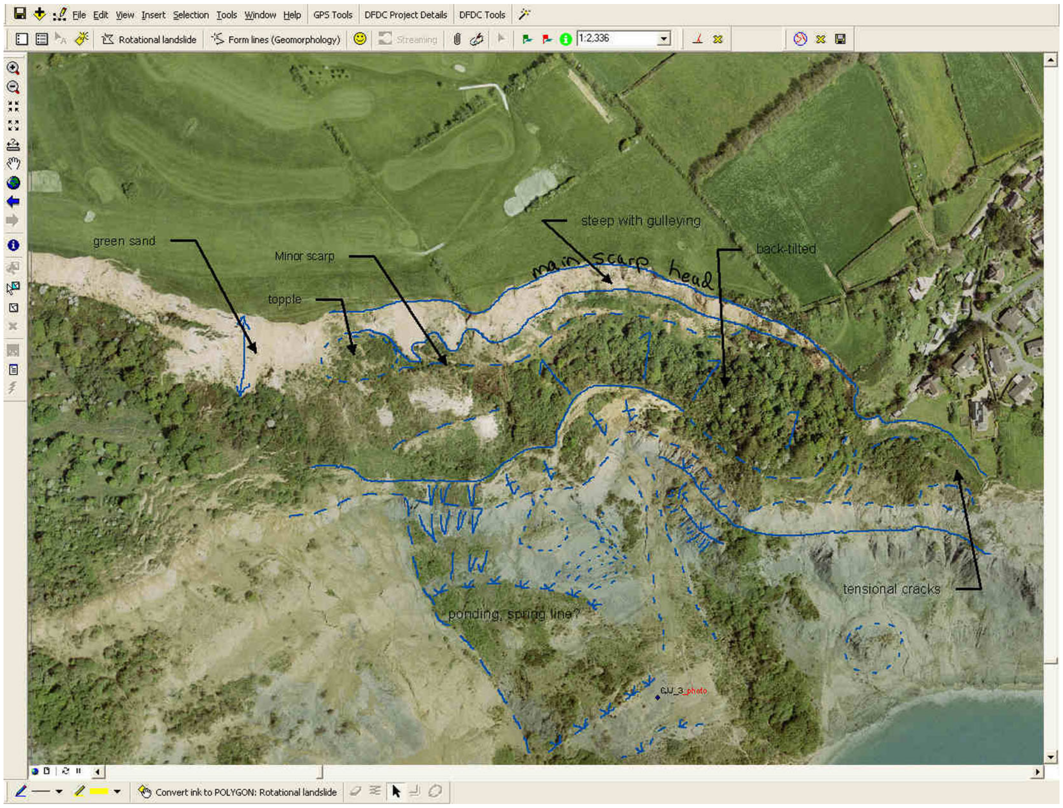

Figure 3. A screen grab of the GUI using data from a landslide at Blackvenn in Dorset, England. Points, lines, and polygons can be added with ease, as can handwriting, either through OCR or left in its native form. Airphoto base image is copyright of UKP/Getmapping Licence No. UKP2006/01.

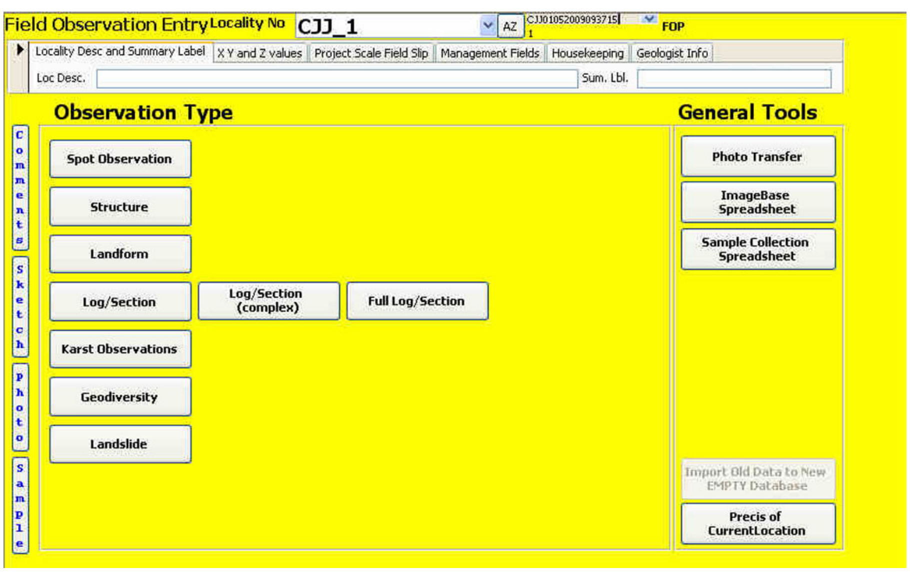

Figure 4. The master form from which modular data (including sketches) can be recorded in a relational database.

specialists, and so on, so that relevant modules of the system are explained in sufficient detail whilst others that might not be of interest to a particular mapping domain are reviewed but not dealt with in great detail.

ArcGIS is the prevalent GIS software in BGS at the moment; therefore, despite the addition of many buttons and tools in our system, the graphical user interface (GUI) of BGS·SIGMAmobile has retained much of the standard ArcGIS appearance. This ensures that the system is easier to learn because most of our geoscientists already are competent in the use of ArcGIS.

Hardware

The first hardware used by BGS was the Itronix GoBook (*http://www.gd-itronix.com/*) and, subsequently, the GoBook DuoTouch. The GoBook specifications included an IP54 ruggedness rating, 8.4-inch transmissive (dual mode active and passive) screens, a Pentium M 1.1 GHz processor, 1280 MB of RAM, a 40 GB hard drive, and integrated GPS. When equipped with a single internal (main) battery, they weighed 2.1 kilograms (kg) and had a nominal battery life of 3.5 hours. An additional battery could be 'piggy-backed' onto the back of the unit to provide additional power. The main (internal) battery can be changed but the procedure requires a screwdriver to remove a cover, so this was not recommended in the field. Whilst it is understood that the advertised battery life is nominal, and is greatly affected by the external temperature, screen brightness, and processes running (GPS, WiFi), it was our experience that the battery rarely provided power for 3 hours even for carefully maintained or new batteries. Furthermore, despite following the maintenance and calibration instructions, it was our experience that the batteries rarely lasted more than a couple of years before refusing to accept a charge. We also found that the screens had two weaknesses:

1. They were difficult to view in bright sunlight. This was partly addressed by the DynaVue system (*http://www.gd-itronix.com/index.cfm?page=Products:DynaVue*), but on the GoBooks it seemed to produce a grid pattern on the screen that was distracting to some users.

2. They were very prone to scratching, and protective transparent screen covers further reduced the visibility.

More recently BGS moved to a hardware system with a larger screen and longer battery life, namely the Xplore iX104 series (*http://www.xploretech.com/index.pl*). Also IP54 rated, the units that were available when ordered by BGS use a 1.2GHz processor, the screens are 10.4-inches diagonally, the nominal battery life is 5 hours, and the weight remains at 2.1 kg. In our experience, the screens are also more scratch-resistant than the GoBooks, whilst also being much easier to read in bright conditions, and the larger size is much preferred by the field staff. The batteries are warm-swappable and do not need to be 'piggy-backed'. Whilst the iX104 is more rugged than the GoBook, we have had several screens break when dropped in the field, and we have found replacing them to be very costly. In our experience it generally takes 6 weeks for the repaired unit to be returned from the U.K. reseller / supplier, and it needs a full reinstallation of all software and systems upon its return, which burdens us with a large overhead of IT support.

A recent addition to the BGS hardware store are two GETAC V100 (*http://www.getac.com*) rugged touchscreen notebooks, with screens that rotate to enable the kit to transform into rugged Tablet PCs. The specifications at the time of writing include a 10.4-inch screen, 120 GB hard drive, 1 GB of RAM, integrated GPS, battery life of 8 hours, and an IP54 rugged environment rating. Clearly, computing technology develops quickly and this is the preferred system used by BGS staff. The integrated keyboard provides additional functionality and flexibility, whilst the nominal 9-hour battery life (at 1.95 kg) is a bonus. The GPS antenna is flush with the tablet casing so is not prone to damage when the unit is being carried or if it is dropped. The hard drive can be removed easily and swapped to another unit. A brief review of hardware, with additional photographs, can be seen at *http://www.bgs.ac.uk/science/dfdc/home.html*.

Case Studies

BGS·SIGMAmobile is used extensively in traditional mapping and other more specialised projects across the United Kingdom and overseas in Africa, the Middle East, the USA, and elsewhere. The author has personal experience using the system on a GETAC in the deserts of the United Arab Emirates (UAE) from January to March 2009, on an iX104 during successive field mapping campaigns in Ghana, and on a GoBook over several months of field mapping in Madagascar, whilst it has also been used on an oil exploration project in Tajikistan (Jordan and others, 2009). The UAE, Ghana, and Madagascar include highly varied terrains and climatic conditions such as desert, tropical rainforest, savannah, and estuarine/coastal zones, and experience at those locations forms the basis for this multi-location case study. Systems were set up in each project to gain maximum benefit from BGS·SIGMAmobile. These three projects have in common such facts as:

- large areas needed to be mapped in very short timescales, and so efficient use of field time was essential;

- large amounts of disparate data (such as aerial/satellite imagery, airborne geophysics, and historic geology and topographic maps) were required in the field;

- navigation was often difficult;

- the clients were keen to see modern mapping techniques utilised.

A current BGS mapping project in the UAE includes field teams of six BGS geologists, with each geologist equipped with a rugged field device. The majority of staff used iX104s, while the author took the opportunity to test the newly released GETAC hardware. Figure 5 illustrates some of the ways that the system was employed in the project. Whilst paper plots of the satellite imagery were brought as backup (fig. 5A) the author did not make use of them at all, finding that the imagery was used more efficiently 'live' on the rugged field computer, with the traverse lines plotted onto a series of base layers such as Landsat ETM satellite imagery (fig. 5B). The imagery was acquired from NASA and processed by specialists in the BGS Earth and Planetary Observation and Monitoring Team. BGS·SIGMAmobile in its most basic form was used as a navigation aid (fig. 5C) with a GPS location symbol guiding the route-finding across the remote desert landscape, which is devoid of any roads or acknowledged route ways. When an outcrop or suitable exposure was located in the field, the data recording functionality of BGS·SIGMAmobile was used (fig. 5D). Periodically, the field teams met in the UAE field base, and all of the data (including points, lines, polygons, and all associated relational data and photos / sketches) were shared, linework was cleaned, and new traverses were planned (fig. 5E). The digital point and line data were used as a basis for the maps and reports that will be output from the project.

Inevitably, some staff found the move to the digital working environment easier than others, but because of the team environment, support was available to those less confident / capable with the new techniques. The desert environment did reveal some issues with the hardware; for example, on occasion the iX104s struggled to gain and hold GPS lock, whilst the GETAC never had such difficulties.

As part of a World Bank project, the author spent two seasons mapping the geomorphology of 255,000 km^2 of Madagascar at 1:500,000 scale. Prior to the use of BGS·SIGMAmobile, it was not uncommon to transport up to 30-35kg of paper plots of maps, satellite images, geophysical data and reports / papers to the country for a single mapping campaign. This author required no paper plots when the digital

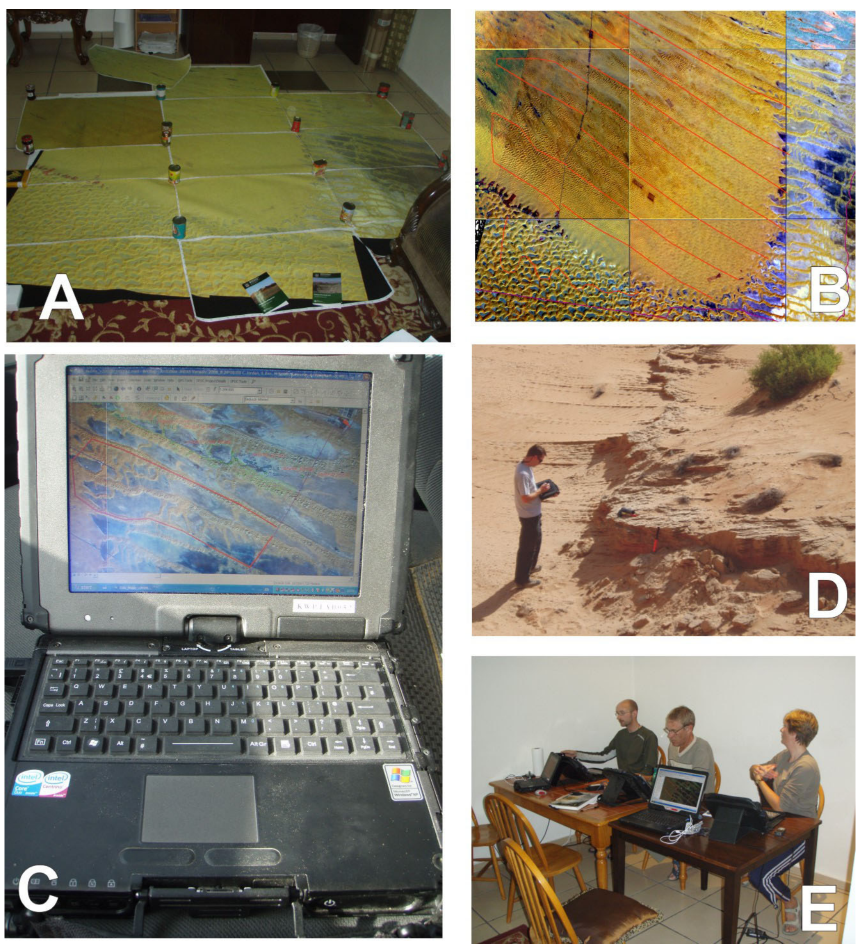

Figure 5. Images from the UAE mapping project, 2009. (A) Paper plots laid out on a floor; (B) same area as A illustrated in a GIS with the traverse lines annotated in red; (C) BGS·SIGMAmobile as a navigation aid, on the passenger seat of the 4x4; (D) GETAC used in the field with a stylus; and (E) staff cleaning / comparing / sharing their digitising in the field office.

field system was used. As in the UAE, one of the primary benefits of the digital system was basic navigation, both when traveling by road and also when conducting traverses by foot. Whilst the system commonly was used to collect point information, the main usage was to record geomorphological linework. Following basic topological cleaning whilst in the field, a legend was added by BGS Cartography staff in the United Kingdom, and the final maps were produced in a streamlined and efficient workflow.

In Ghana, BGS field teams were deployed over 3 years to remap the Volta River and Keta Basins (a combined area of approximately 98,000 km^2), as part of an airborne geophysics project funded by the European Union and conducted in cooperation with the Ghana Geological Survey Department (GSD). The airborne geophysical data were acquired by Fugro Airborne Surveys Ltd., and counterpart support was supplied by the GSD. Vast amounts of remote sensing (airborne and satellite) data were acquired during the project, along with gigabytes of scanned maps and reports, and one of the main challenges was to make these data available in the field. Having BGS·SIGMAmobile in Ghana ensured that navigation was made easier, data were collected to accepted standards, and the baseline data were to-hand when required at the outcrop or when travelling between exposures (Jordan and others, 2008). The pre-fieldwork interpretation was undertaken digitally and then added to or modified on BGS·SIGMAmobile in the field before being transferred back to the master GIS for map production.

Summary

The challenge of developing a digital mapping workflow is being met by the British Geological Survey using several bespoke systems (fig. 2), one of which is the field data capture system called BGS·SIGMAmobile. The system has been used successfully in projects across the globe, in varied terrains and climatic conditions. Brief examples from the UAE, Ghana, and Madagascar highlight the successful application of the system to current and recent mapping projects. BGS is still modifying the system to make it more efficient, to add new input mechanisms, and to add new modules, but it has proven its worth to our field staff with encouraging feedback being received by the development team, including statements highlighting the preference of the digital system over the traditional pencil and paper notebook and maps.

As noted above, the system is still being upgraded to increase functionality and efficiency, but the current system is available for free download to both academic and commercial users from *http://www.bgs.ac.uk/science/3dmodelling/sigma.html*. Users need to have their own ArcGIS and Microsoft Access 2003 licenses onto which the BGS system will run. When downloading the system, users must agree to send any modifications and (or) upgrades to BGS so that they can be added to future releases if appropriate. We hope that making the BGS system freely available will encourage shared development of an international standard system, leading to increased cooperation and knowledge exchange. We invite you to download a copy today.

Acknowledgments

Sincere thanks are due to the dedicated team of GIS and database developers for building an award-winning system of which they should be truly proud. We were helped by field staff who provided constructive feedback, while the support of management throughout development and implementation is gratefully acknowledged. This paper is published with the permission of the Executive Director, British Geological Survey (NERC).

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A New Delaware DataMIL

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The Delaware Geological Survey (DGS) Delaware Data Mapping and Integration Laboratory (DataMIL) team has modified and improved the DataMIL Web site in several ways to ensure that the Delaware GIS community and the citizens of Delaware can take full advantage of Delaware's Spatial Data Framework Layers (Aerial Imagery, Boundaries, County Parcels, Elevation, Geographic Names, Surface Cover, Transportation, and Water Features). These important basemap layers are used regularly by State, county, and local agencies, as well as by planners, environmental and engineering consultants, educators, developers, realtors, and the public. DataMIL has served Delaware's framework layers since its release in 2002, and the data are part of the National Spatial Data Infrastructure (NSDI).

The DataMIL also serves Delaware 7.5-minute topographic maps that replace the U.S. Geological Survey (USGS) 7.5-minute Primary Map Series for the State of Delaware. The DataMIL topographic maps comprised the up-to-date Spatial Data Framework Layers from the DataMIL. These maps can be downloaded as PDF files from the DataMIL site under the "Topo Maps" menu. PDF files can be used on the computer or printed. The University of Delaware Library, a Federal Depository Library, archives one statewide set of these topographic maps each year to provide a historical archive of change.

Instructions for using the Web site can be found under the "Need Help?" menu in the upper right side of the page banner. When entering the revised DataMIL site (*http://datamil.delaware.gov*), users will see a data catalog and be able to preview each layer in a "map viewer," read the metadata, or download the entire statewide dataset. The data layers are also searchable by category, by keyword, and by spatial search. When exploring the metadata records, users can share these data with colleagues through email and social networking sites. Another helpful item is a GeoRSS feed that notifies users of recent changes on the DataMIL site. Lastly, the site makes use of a Google Map interface that allows large datasets to be available for download. The DataMIL Tiled Data Distribution page is an easy way to click and get tiles of imagery and elevation raster datasets for the entire State.

We invite you to visit the Web site and see the changes at *http://datamil.delaware.gov*. If you have comments or questions, please feel free to contact the DGS DataMIL team via e-mail at *DataMIL-DGS@udel.edu*.

Credit Where Credit's Due: Developing Authorship Strategies at the Journal of Maps

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Introduction

As organizations seek to professionalize the workplace, they are increasingly under pressure to both enhance the skills base of their staff and subsequently measure the value that each individual contributes to the performance of the organization. As a result, it is common for many staff to undergo an annual appraisal of their performance, measured against the criteria for their position. Within academic and research institutions the publication of the outputs of work are considered the primary method of dissemination and is a key measure of "performance," as it is easy to quantify. Whilst, at its simplest, this can be calculated as the number of publications produced by an individual, such a measure is fairly crude in that it does not take into account the authorship position or the "quality" of the publication outlet. It is also possible to measure the "impact" of a publication through the number of citations it receives, although this does not necessarily equate to the quality or significance of the work. Outputs such as maps, databases and digital models that do not conform to these usual academic measures are less easy to measure using performance indicators. Authorship is also difficult to quantify for work that is not directly related to the academic content of a publication; for example, cartographers and database programmers are integral to the production of a geological map yet may receive no formal credit for their input. This paper briefly reviews the processes for crediting input to published research and survey work, highlighting some of the deficiencies that this introduces. This forms the basis for describing strategies introduced at the Journal of Maps to provide a greater level of flexibility and granularity in allocating authorship credit. This is illustrated using the British Geological Survey's (BGS) 1:625,000 Bedrock Geology Map of the United Kingdom as an example.

Authorship Credit

The publication of research forms a primary method of dissemination for many academically related professions, including geological mapping. High status journals are generally regarded as the output of highest esteem, and these form a permanent archive that can be accessed by future academics. Figure 1 shows an example of title information at the top of an article (Smith and others, 2006), noting the affiliations of individual authors. This provides appropriate credit and it is general practice for the "lead" author to be listed first, with decreasing input to the publication reflected by the authorship position.

The impact of an item of published work is quantifiable through the number of citations it receives, and this simple metric can be used to measure its "quality." Indeed the usefulness of the citation's metric forms the basis for an

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Geomorphology 76 (2006) 148–165

GEOMORPHOLOGY

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Geomorphological mapping of glacial landforms from remotely sensed data: An evaluation of the principal data sources and an assessment of their quality

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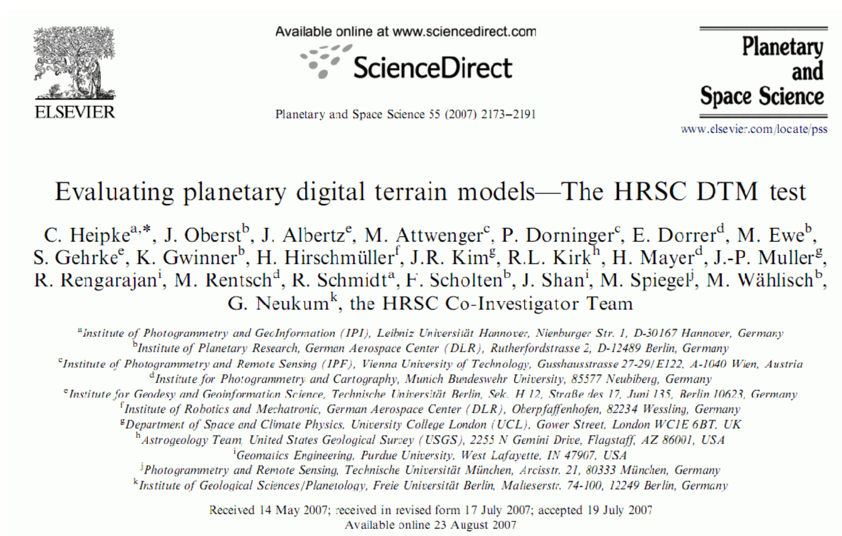
Received 27 July 2005; received in revised form 1 November 2005; accepted 2 November 2005
Available online 19 December 2005

Figure 1. A typical journal article with title, authors, and affiliations (Smith and others, 2006).

assessment of the quality of individual journals known as the "Impact Factor" (Thomson Reuters, 2009) which calculates the *average* number of citations over a 2-year period. This has been extended to individuals through a self-subscription system (ResearcherID, 2009) where a range of metrics is displayed. Within the United Kingdom, the Higher Education Funding Council for England (HEFCE), which funds teaching and research at universities, is reviewing the use of citation metrics in rating the quality of research in individual research departments (HEFCE, 2009).

The performance of individual employees can therefore in part be quantified based upon the number of authored publications and number of citations, and can further take into account authorship position and impact factor of the individual journal. If citation metrics are to be used as performance indicators, then it becomes increasingly important for individuals to receive credit for all "work done"; however, there is no formal or generally accepted procedure for ascertaining who should be listed as author on a publication. In fact the opposite situation, that of "gift authorship" (Williamson, 2003), is a known problem particularly in academic institutes where a head of department may be named as an author regardless of whether or not the person has had input to the research and subsequent publication. For research where many have been involved, possibly over a number of years, the general practice is to name all "workers" on resulting papers; is that the right approach? Figure 2 displays title information for Heipke and others (2007), which not only lists 22 individual authors, but the entire HRSC Co-Investigator Team. This is commonly used by centrally funded science teams but raises the following query: what is an author? Is it the person(s) who writes the paper or writes a section? Someone who edits the paper or perhaps was just involved in the project? What about data or map production? These are difficult questions to answer and demonstrate that authorship "rights" are contentious and will remain so if authorship is used as a measure of performance. As a result of this problem, "Acknowledgements" have long been used as an informal method for recognizing the input of individuals to a project (fig. 3); however, because this is an informal means of recognition, it does not convey any measurable credit. It should be noted that within the Natural Environment Research Council (NERC; the parent body of BGS) maps, databases, 3D models, and other outputs that are innovative or require high-level technical input are recognized and given equal



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Planetary and Space Science 55 (2007) 2173–2191

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Evaluating planetary digital terrain models—The HRSC DTM test

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Received 14 May 2007; received in revised form 17 July 2007; accepted 19 July 2007
Available online 23 August 2007

Figure 2. An example of the use of multiple authors as a means of recognizing input to a project (Heipke and others, 2007).

> **Acknowledgements**
>
> We thank Steve Booth and James O'Brien for their assistance with this work. Reviews from Ian Evans and John Shaw helped improve this manuscript. The NEXTMap DEM data was kindly supplied by the British Geological Survey.

Figure 3. The use of acknowledgements for providing informal credit (Smith and others, 2009).

status to papers within the appraisal and promotion processes. However, these outputs are not easily included into more widely accepted citation indexes and may therefore have no credibility outside of NERC.

Within academic publishing, maps are a nonstandard publication that falls outside the traditional "manuscript," incorporating input from many individuals. In such instances how do we ascertain the input of those involved? How do we provide appropriate credit? For paper maps, authorship is usually given in the title box, but that may only include the chief surveyor for the mapped area, or the Executive Director of the organization, or it could include all who had scientific and cartographic input to the map. For the BGS, guidelines are provided but they have been applied variably such that for some maps all contributors including database experts, aerial photo interpreters, and cartographers are listed in the title box, on others the chief surveyor, director, and cartographer are listed, whereas on others the cartographer's name is put in the opposite corner of the map to the main title. As well as being an inconsistent presentation of main "authors" and contributors, it is not clear how the credit for the map generation is spread among all contributors. Furthermore, the situation is complicated when "Sheet Explanations" and memoirs are published, as they may not relate to a single map.

For digital maps, geographical information system (GIS) data layers, and digital 3D models, which are now increasingly the output of a survey or geological research project, there seem to be no rules as to how authorship is credited and presented and how that credit might be used as a measure of performance to align with current academic practices. In a GIS dataset the attributes of each map feature contain information about that feature and could also contain authorship details, or perhaps more appropriately the metadata could contain author/contributor details; therefore an agreed and recognized structure needs to be established. However, feature-level authorship remains aspirational with current common practice concerned with product-level data. Metadata could also be used to provide author details for digital models and other datasets that replace or complement printed maps as output.

Currently, national and international spatial data metadata standards, such as GEMINI 2, ISO 19115:2003, e-GMS, and INSPIRE, all include a category for creator, originator, or responsible party that are approximately equal, and also suggest that an organization or job title rather than an individual should be named, with a view to identifying legal responsibility rather than attributing the work. For GIS datasets, which include digital map data, BGS adheres to the ISO 19115 metadata standard requiring that the creator be recorded as "The name of an organization or individual that developed the data set." It is not BGS standard practice, however, to name all those who might be involved in creating a map or GIS dataset and it is very recent practice to have other than high-level discovery metadata at all. For individual paper maps, metadata has never been provided; instead, this is created for a map series, with no named cartographers.

Authorship Strategies

At the Journal of Maps (JoM) several strategies have been implemented in order to provide alternative, measurable methods of formal credit on journal articles. These include the use of map authors, "secondary" authors, and the publication (and citation) of data. Regrettably these are not currently counted as a formal citation by Thomson Reuters Web of Knowledge. This may impede wide recognition of map, data, and modeled output as citable publications; alternatively, this recognition could be encouraged as part of a widening of citation index application. These different strategies are discussed in more detail in the following sections.

Whilst the primary citable output for the JoM remains the article that accompanies the published map, it is important to note that within institutional settings the (academic) author(s) of the article may be entirely different from those of the map, even though they together comprise a single publication. The latter can incorporate field workers, cartographers, graphic designers, and database programmers. In such instances it is appropriate to cite the map separately, for example:

Floyd, J.D., Addison, R., Reay, D., Leslie, A.G., Pharaoh, T.C., Myers, A.H., Turner, P., Arbon, J.W., and Cooke, I.C., British Geological Survey 2009 Map, *in* Smith, A., A new edition of the bedrock geology map of the United Kingdom: Journal of Maps, v. 2009, p. 232-252.

Secondary authors form a second "tier" of authorship and provide the means of recognizing significant input to a project without necessarily assigning the status of a full author (and separate from those not directly involved in map production). Figure 4 illustrates an example of a title page from the JoM listing both primary and secondary authors. This provides credit for "work done," formally notes an individual's affiliation, and can be cited separately. In this example, the secondary author would be cited as:

Harrison, S.K., 2008, Secondary Author, *in* Smith, M.J., Knight, J., and Field, K.S., Glacial striae observations for Ireland compiled from historic records: Journal of Maps, v. 2008, p. 378-398.


Journal of Maps, 2008, 378-398

Glacial striae observations for Ireland compiled from historic records

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(Received 5th August 2008; Revised 14th October 2008; Accepted 17th October 2008)

Figure 4. The use of secondary authors in a published article in the Journal of Maps.

The JoM has been publishing data *with* journal articles since its launch in 2005 (M.J. Smith, 2009). This enables the data to accompany the article and maximizes "immediacy" which is of significant benefit to the reader. However, it has limited functionality because the data remain embedded within the published PDF. It also means that the PDF does not meet the PDF/A standard, which is designed for the long-term preservation of electronic print materials (NDIIP, 2009). The JoM requires that data deposited within the PDF must conform to one of several data formats selected for being openly published and well supported; this is intended to maximize the archival potential of the data for future users. Within the context of citation metrics, data forms a section within the published article and should be cited separately, as shown below:

Dunlop, P., Data, *in* Dunlop, P., and Clark, C.D., 2006, The Distribution of Ribbed Moraines in the Lac Naococane Region, Central Quebec, Canada: Journal of Maps, v. 2006, p. 59-70.

A further solution for map publication currently under review is the publication of map editions. Where an author wishes to update a map based upon the correction of mistakes or the addition of new knowledge, this can be published as a new edition. This also allows the updating of primary and secondary authors, providing an opportunity for those involved in the production of a new edition to receive appropriate credit. Within this context it is worth noting that PDFs are a very flexible publishing medium that allows the incorporation of single and multiple map sheets, audio, video, and 3D models, as well as direct hyperlinking out of the document.

Case Study: BGS 1:625K Bedrock Geology

Development, production and publication of the 1:625,000-scale series of national bedrock geology maps for the U.K. has been a prolonged and complex process to which many staff from multiple fields of expertise have provided input, but no single author could easily be established. The BGS has been in existence since 1835, and therefore many staff since its inception have contributed to the national U.K. maps that have been compiled from their (generally) more detailed work. The 1:625K national map has been compiled from tiles that were published at a variety of scales over a 175-year period. The staff inputs to each component map tile can include a vast range of expertise including geologists (field mappers, stratigraphers, engineering geologists, structural geologists, remote sensing geologists), geomorphologists, geochemists, geochronologists, geophysicists, paleontologists, cartographers, programmers, 3D modelers, lab technicians, database compilers, and project managers. If we consider that many hundreds of staff have been directly and indirectly involved in the map production since 1835, the question is now asked, how can we give credit where it is due? Below we discuss authorship credit related to the 2001 (4th edition) in comparison to the 2007 (5th edition) and the digital DiGMapGB versions that are available for download from the BGS (*http://www.bgs.ac.uk*).

The title box for the 4th edition acknowledges publication by the then-Executive Director with the statement "*Published 2001, David A Falvey PhD, Executive Director, British Geological Survey*", but no credit is given to geologists, cartographers, or others involved in production of the map. The development of the 5th edition involved coordination and approval of proposed updates to the map data, which was managed by three people: a geologist with an overview for Scotland, a geologist with an overview for England and Wales, and the digital map manager who ensured that standard procedures were followed and that development of map face data and marginalia followed procedures similar to "usual" digital map compilation. The digital map manager also interfaced with the cartography team, for which there were lead data capture and map design personnel, coordinating the input of others. A team of geologists developed a key for the geology, to be used in the map legend. This had input from a range of personnel and was approved by the Chief Geologists for England, Scotland, and Wales (not authors but people who had significant scientific input to the outcome). The title box on the southern sheet of the 5th edition (2007) carries 12 named credits (listed below and shown in figure 5), whilst the northern sheet has 13 named credits:

- 2 geologists credited with geological interpretation and map compilation
- 1 geologist who produced the geological cross sections

- 1 geologist who supplied deep geology information
- 2 cartographers who prepared the data
- 2 cartographers who undertook the cartography
- 1 project manager
- 1 Programme Manager
- 1 Director
- The BGS Executive Director.

Copies of the paper maps can be ordered online whilst the 'raw' digital data can be downloaded in a variety of GIS formats from the BGS website. At the time of writing, the GIS digital data do not include credits; however, the map will soon also be published in PDF format on the BGS Web site and will carry the same credits as the 5th edition, while the PDF metadata will include additional authorship details. The map (Floyd and others, 2009) and article (A. Smith, 2009) have also been published in the Journal of Maps.

It is seen as a very positive development that between the 2001 and 2007 versions the number of BGS staff credited with input to the published paper maps has increased from 1 to 12 for the southern map and to 13 for the northern map. This is clearly a huge improvement. However the question still needs to be asked: is this enough, or is there a realistic way to credit the role of other staff who contributed to the map or its predecessors? The four options available for crediting input to the maps are:

1. return to the format where only the Executive Director is acknowledged;
2. include a 'catch-all' credit statement thanking all current and past staff who may have had an input;
3. attempt to list all staff who have contributed to previous maps, and the current version (possibly by using the secondary authorship approach being pioneered in the JoM);
4. use the edition or versioning approach mentioned above to ensure that, from the most recent version onward, we credit the main compilers and cartographers at the very least?

Option 1 is a step backwards in terms of providing credit where it is due, and is therefore not considered further. A brief statement acknowledging that the map is the culmination of many years of survey and research (as noted in Option 2) is certainly viable, whereas the third option (listing all staff) is unrealistic. It therefore seems that the system currently employed by BGS, where credit is given per edition (Option 4), along with a 'catch all' statement (Option 2) is the most favourable option for the published 1:625K maps.

As listed above, credit can be given to data compilers as well as those who create a final (digital) map product. When databases, 3D models, and such have been created prior to map production and the map is derived from those datasets, secondary credit could go to the "authors" of the original data from which a map is compiled. Currently this is not standard practice in BGS and perhaps not in most mapping organizations.

Conclusions

There has been an increasing movement within organizations to professionalize the workplace and measure the "value" or "contributions" of individuals as part of an internal appraisal system. Within research and academic institutions

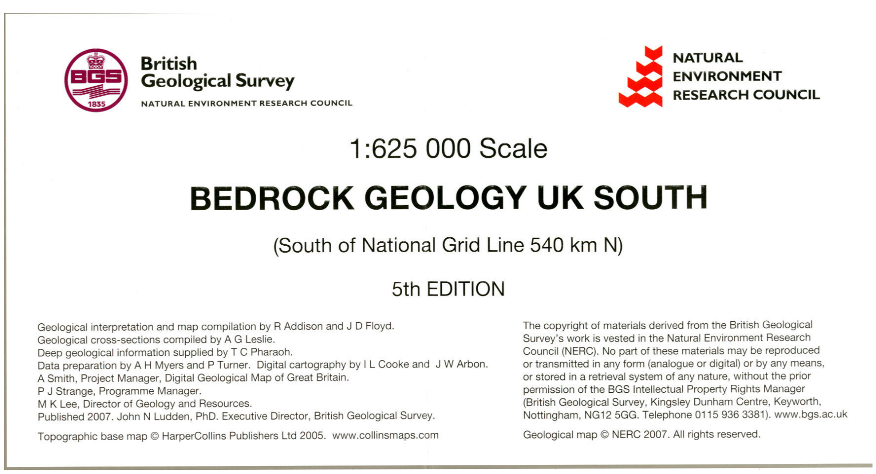

Figure 5. BGS map title box with all contributors named (British Geological Survey 1:625,000-scale Bedrock Geology UK South, 5th Edition).

this may involve listing the number of publications an individual has accumulated, in addition to the number of citations and authorship position. For map outputs, the citation, and inclusion of all contributors, is currently poorly defined. Authorship credit for paper maps has varied according to era, organizational practices, and product type, both within BGS and other mapping agencies. Where an individual has provided significant input to a product, whether it is a database, map, model, or paper, a mechanism needs to be provided by organizations and journals to recognize that input. Most maps, databases, and GIS layers carry significant metadata that lists information such as the originator of the data; therefore, ways must be found to recognize and name that input systematically when the results are published in the variety of formats that are now available.

Current metadata standards for spatial data are not designed to credit authorship of maps or other data outputs; they are aimed at enabling better understanding of the output itself and its origins, not its originator. The Journal of Maps provides a citable route and publishing format through which maps can be published and authors formally credited. The JoM has adopted a range of innovative citation standards including secondary authors, data authors, and map authors, which could be adopted more widely. The challenge to follow will therefore be for academic and other bodies to recognize the significance of maps, 3D models, and other datasets in the same way as for written papers and reports.

Acknowledgments

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USGS Topographic Maps from *The National Map*

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Introduction

This paper was presented prior to the U.S. Geological Survey (USGS) topographic mapping project's release of "Digital Map – Beta," which was the newest version of USGS's topographic maps. Since then, the project has evolved to releasing in December 2009 the "US Topo" version of the new topographic maps, with integrated contours and water features (hydrography). This paper will address what was presented at DMT'09 and in brackets the current status of the project.

The National Map Vision

The National Map (*http://nationalmap.gov/* and video at *http://gallery.usgs.gov/videos/187*) is a seamless, continuously maintained, nationally consistent set of base geospatial digital data. It provides a foundation for science, land and resource management, recreation, policymaking, and homeland security. It provides geospatial data for downloading and services for Geographic Information System (GIS) users. *The National Map* contributes to the National Spatial Data Infrastructure as public-domain data that support product generation, services, analyses, modeling, and other applications at multiple scales and resolutions. The geospatial data contained within *The National Map* are built on partnerships and standards, and the data are freely available over the Internet.

The National Map is being developed in three phases, 1.0 through 3.0. Phase 1.0 is accomplished; it consisted of initial population of the eight data layers. The eight layers are for imagery, elevation, hydrography, geographic names, land use land cover, transportation, structures, and boundaries. The USGS is directly responsible for the first five layers in this list. Responsibility for the other layers can be found in the Office of Management and Budget (OMB) Circular A-16 (*http://www.whitehouse.gov/omb/circulars_a016_rev*). Phase 2.0 is in progress, and addresses data consistency, integration of the data layers, digital topographic maps, and print-on-demand maps. Phase 3.0 will address a user-centered design, feature-based data structures with ontology-driven data access, intelligent-knowledge base, spatio-temporal data modeling, and increased quality awareness with a user-centered Web interface.

The components of Phase 3.0 are defined in more detail as follows: "User-Centered Design" – the goals of this design process are to: (1) improve usability of the human interface; (2) provide easy access to high-quality maps in various media; and (3) support high-quality printing for all users. "Feature-based data structures" – all data in *The National Map (phase) 3.0* will be accessible as individual features; for example an entire stream, such as Turkey Creek, will be accessible as one feature. Attributes and relationships will be attached to individual features through an ontology. "Ontology-driven data access" – an ontology specifies feature semantics for richer data models. The ontology becomes the basis of data access. The ontology for *The National Map* will include all features, attributes, and relationships with the individual parts of a feature structured in an accessible hierarchy. For example, the source and mouth of a stream will be related in the ontology as will the parts of a terrain feature such as a canyon, which would include the canyon floor and walls. "Intelligent-knowledge base" – data, methods, procedures, and heuristics combine to provide individual features with "knowledge" of their own behavior. For example, for each feature there will be instructions for how to display it with appropriate symbology at a given scale. Features will include knowledge of their inter-relationships with other features. For example, a stream's bounding hills and ridges will be available by name from the stream feature itself. "Spatio-temporal data modeling" – *The National Map* will be built on a data model that supports changes in geographic features in both space and time. For example, a coastline in 1950 will be different from that of today, yet it is the same feature, and will be structured as the same feature with different geometry and perhaps different attributes in the two time periods. "Quality-awareness" - *The National Map* will be built on a data model that includes resolution and accuracy information on a feature-by-feature basis. That is, each feature will include its own information about data quality.

The National Map viewer will be improved with scale-dependent symbology, georeferenced displays, attribute queries, and increased national coverage of data. [This new viewer is planned to be released in April 2010. It is now in beta-version testing.]

USGS Geospatial Liaisons

USGS has liaisons that represent partnerships in all 50 States. The people in these liaison positions cultivate and maintain long-term relationships with partners, develop partnerships and support agreements, advise and consult on geospatial data and technology, coordinate with partners on the Federal, State, and local levels, and are the 'local face' of *The National Map*. For a list of liaisons, their contact information, and the State(s) that they represent, see *http://liaisons.usgs.gov/geospatial/*.

New Topographic Maps From *The National Map*

The National Map is the source for the features presented on USGS's new topographic maps. Therefore, the topographic maps are a derivative product made from geospatial data residing in *The National Map.* These geospatial data are available for viewing, services, and download from *The National Map* viewer. [*The National Map* viewer, at *http://viewer.nationalmap.gov/viewer/*, has user-definable instances of base maps upon which other GIS data services can be mashed-up in the viewer. At the time this paper was given the new topographic map was about to be released as the "Digital Map – Beta." This version of maps is still available from the USGS Store, at http://store.usgs.gov. As of December 2009, the US Topo, at http://nationalmap.gov/ustopo/index.html, with integrated contours and water features, was released and these products are now being generated. The US Topo maps are also available from the USGS Store or for emergency response personnel and organizations, from the Hazards Data Distribution System.] Following are *The National Map* sources for the feature types that will eventually appear on the US Topo maps:

- orthoimage – National Orthoimage Quadrangle Dataset (DOQ)
- elevation – National Elevation Dataset (NED)
- hydrography – National Hydrography Dataset (NHD)
- transportation - National Transportation Dataset (NTD)
- boundaries – National Boundaries Dataset (NBD)
- structures – National Structures Dataset (NSD)
- vegetation – National Land Cover Dataset (NLCD or MRLC (Multi-Resolution Land Cover or Characteristics))
- names – Geographic Names Information System (GNIS).

Grids and quadrangle-level metadata for the topographic maps are not a data theme in *The National Map*. Instead, they were generated to be part of the digital topographic maps.

New Topographic Maps – A Description

The new topographic maps, in two versions - the "Digital Map - Beta" and the US Topo, will be a set of nationally consistent maps that can be used electronically or plotted onto paper. [Between 2010 and 2011, the USGS will complete national coverage that will comprise the "Digital Map-Beta" and the US Topo maps. The US Topo maps will replace the "Digital Map – Beta" maps in 2012.] The new maps will be a digital GeoPDF-formatted file with each feature type shown on a separate layer. The GeoPDF is not the generic PDF version, but a proprietary product of TerraGo Technologies, Inc. The digital maps will be georeferenced and will contain user-interaction tools. They will be accessible on-line from a home or office computer at no cost. They will be interactive, contain richer content that is quality assured to standards, and will be functionally superior to the Digital Raster Graphic (DRG) maps that USGS generated in past years. These new topographic maps will remain in the public domain, require no copyright, and will have features symbolized from authoritative data. Generally, the authoritative data come from Federal agencies. USGS is the authority for imagery, elevation, hydrography, geographic names, and land use - land cover data. The maps will be plottable or lithographically printable to map scale or any other scale the user chooses. USGS is committed to improving these maps over time.

New Topographic Maps – The Strategy

USGS will create this new generation of topographic maps by following the 3-year National Agricultural Imagery Program (NAIP) collection cycle. Thereby, each topographic map, in the lower 48 States, will be updated once every 3 years with the latest NAIP imagery and *The National Map* data. People who want more current geospatial data can obtain them directly from *The National Map.* The initial production will start in 2009 with “Digital Map – Beta” products containing a digital orthophoto image, roads, and names. [The “Digital Map – Beta” product was released in June 2009. Approximately 13,000 maps were made that year.] In the following years the content of these maps will be enhanced as the geospatial data become available in *The National Map* and technical processes are improved or implemented. For example, in 2010, contours integrated with hydrography will be added to the map. [This was accomplished and included in the US Topo maps, which were released in December 2009.] In years to come, USGS plans to add layers containing high-resolution scans of historical topographic maps for each quadrangle.

New Topographic Maps – Longer Term Issues

In many cases, there are no national-coverage public-domain data to use in making the new topographic maps. Feature types or data themes (layers) for which this is a problem include boundaries, Public Land Survey System (PLSS), vegetation, structures, and transportation features other than roads. [USGS is now working through its partnership office liaisons to discover suitable data.]

Data integration of digital geospatial data is very costly, time consuming, and difficult to achieve. The lack of integration among the data layers and within a data layer causes poor registration and feature joins. [USGS is now deliberating on what data in *The National Map* should be integrated.]

Relief portrayal is easily enhanced using modern GIS software. [USGS is now investigating how best to make topographic relief more easily understood and interpreted.]

USGS would like to bundle the historical maps with the new topographic maps. However, whenever a raster layer is added to the digital file, it significantly increases the file size. [USGS is now investigating ways to manage the file size while adding additional content to the new topographic maps.]

Scanning Historical Maps

USGS will create a high-quality scan of all published USGS topographic maps, at all scales and in all editions. [Today, USGS is scanning historical versions of each topographic map.] The intent is for these high-quality scans to become an archive and to be freely available to the public. USGS will use partnerships to facilitate collaborative-scanning projects and to minimize duplication of effort.

New Topographic Maps as a Geologic Base Map

USGS’s Graphics Project, that is responsible for making topographic maps, proposed a proof-of-concept test, beginning in October 2009, to use the new topographic maps as a base for geologic mapping. [This project is now in the planning phase.] The test will be targeted at providing an improved digital base map on which geologic features can be mapped.

Why Doesn't Your Model Pass Information to Mine?

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Abstract

For several decades geologists have been making three-dimensional (3D) models. Various proprietary and open-source software tools have been developed which allow geoscientists to produce reasonable 3D representations of the geological system that they are studying. The model they produce is quite often an 'island' of independent information. In the past, this may not have been a significant problem because there were so few models available that it was unlikely to find adjacent models forming islands in the same sea area. However, that is changing, the sea is now getting crowded with island models that can't or won't communicate with each other. The problem is compounded by research in other disciplines -- hydrologists, oceanographers, and atmospheric scientists are creating environmental models which don't take account of the geological sciences or that model them in a simplistic manner. For example, in water resource management a given area can have a 3D geological model, 3D hydrogeological model, a hydrological model, and a precipitation model. These are four models, produced by four disciplines, each using different methodologies, often based in different organisations or universities; of course none of the models pass data or information between each other. Our society needs to manage the water resources, but the models that environmental scientists are producing do not provide a coherent and consistent, single picture for the policymakers. This is becoming increasingly recognised within the European Union (EU). The European Environment Agency recently completed an inventory and recognised that "over the past few decades, a myriad of models geared to depicting, simulating and projecting environmental change have been developed and applied."[1] This is one of many preparative steps for the SEIS (Shared Environmental Information System) initiative which may lead to a future EU Directive and transposition into member countries' legislation.

The British Geological Survey (BGS), a component of the Natural Environment Research Council (NERC), launched a project in early 2009 named "Data and Applications for Environmental Modelling" (DAEM), in preparation for SEIS. The aim of the project is to enable our models to pass data and information back and forth to other models. This paper describes challenges faced by the DAEM Project.

Introduction

Over the next few years, the British Geological Survey (BGS) will focus its activities on key strategic issues related to energy and environmental change. The BGS will address complex environmental challenges requiring decisions in both the short and medium term, including carbon capture and storage, radioactive waste management, natural hazards, resource security, and environmental protection. The 2009-2014 BGS Strategy (BGS, 2009) document has at its heart a number of crosscutting projects designed to address the key

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[1] http://www.eea.europa.eu/publications/technical_report_2008_11

strategic issues. One of these is Data and Applications for Environmental Models (DAEM). The stated aim of DAEM in the BGS Strategy is:

> *Development, application and operational deployment of dynamic geoscience models is at the leading edge of geoscience informatics. It requires complex and sophisticated technological development, especially in the fields of data architecture and standards, spatial informatics systems and knowledge management. This project will build on the technological advances of earlier BGS projects in the fields of data architecture, information management, digital map production, digital field data capture, geographic information and 3- dimensional modelling and visualisation, to develop a data architecture and applications environment that supports the generation of spatial and process models. We will encourage wider community involvement in their testing and application and existing international collaboration, for example in developing worldwide geoscience data and mark-up languages and exchange formats, will be taken forward to incorporate methodologies and best practice for development and use of subsurface models. To maximise their effectiveness and range of applications we will adopt a policy of making our capture and modelling software and systems available to the wider community for testing, research and educational use.*

The scientific problem that DAEM will address has been well articulated by Reitsma and Albrecht (2005, 2006). They recognised that modelling the Earth system involves numerous interacting components, each of which can be further dissected into sub-components that are studied by specialists in a wide range of scientific disciplines. The problem is compounded by the number of research groups and individuals involved in creating, managing, and sharing environmental models. Add to this the existing wide diversity of modelling approaches. Then factor in the requirement to deal with both spatial and temporal data. Furthermore, much of the knowledge about the physical systems that are modelled is held, from a computing perspective, dormant in scientific papers, modelling code, and in the heads of scientists. Finally, the lack of transdisciplinary semantics, or even explicit domain-specific semantics, reduces the ability of linked models to create real understanding.

BGS intends to put in place a framework that provides scientists with data, tools, techniques, and support to address transdisciplinary environmental questions that affect human society. We intend to achieve this by building an open community that will share data, applications, techniques, and environmental models thus enabling collaboration and achieving sustainable solutions. Clearly the BGS will not achieve such an ambitious vision on its own. Instead it intends to be part of a community, playing a leading role within that community.

To achieve these ambitious goals, a considerable number of challenges will need to be faced and overcome; these are described below.

What Do We Mean By Models?

One of the difficulties of transdisciplinary working is terminology. The word "model" means different things to differing scientific communities. Therefore it is worth defining different types of model discussed in this paper:

- Conceptual models
- Framework models
- Discrete Process models
- Linked Process models.

There is also a need to consider the relationship between data and models. A Digital Elevation Model is the result of a modelling process of the land surface. This model, in turn, can be used as input data to other models, for example a rainfall-runoff model. Care therefore has to be taken with terminology.

Conceptual Models

A conceptual model is a descriptive representation of a collection of ideas about how a system of some type functions. The process of developing a conceptual model involves gathering information of various types and developing a qualitative understanding of the physical structure or behaviour of a system. With the conceptual model in place a range of quantitative approaches can be developed to test the validity of the conceptual model and the new information can lead to its rejection or further refinement.

Framework Models

A framework model is a tool to allow scientists to integrate disparate empirical observations into a coherent whole. Such models are used to develop an understanding, in several dimensions, of information that is only partially observed. For example we frequently see three-dimensional (3D) representations of the Milky Way Galaxy. However, it is impossible to empirically observe the whole galaxy from Earth. The models are created by a mixture of observations from Earth and extrapolation from observations of other galaxies. Earth scientists use framework models to understand the geology that can only be partially observed by a range of methods. Such models capture the geologists' observations, concepts, and knowledge in a spatial framework. These may include observing outcrops, mapping topographical features, borehole logs and core, and so on. Geologists use two principal types of framework models; the geological map (on paper [*http://shop.bgs.ac.uk/bookshop/catalogue.cfm?id=2*] or GIS [*http://www.bgs.ac.uk/products/digitalmaps/digmapgb.html]*) and 3D models (*http://www.bgs.ac.uk/gsi3d/*, *http://en.wikipedia.org/wiki/GSI3D*, and *http://www.bgs.ac.uk/science/3dmodelling/zoom.html*). Figure 1 shows the differences between 2 dimensional (2D) and 3D data formats in Earth sciences.

The BGS has chosen GSI3D (Kessler and others, 2009) as the preferred geological modelling package for the production of standardised geological framework models at all scales. In simple terms, the GSI3D software utilizes a Digital Terrain Model as the model-capping surface, plus geological surface linework (maps) and down-hole borehole data to enable the geologist to construct regularly spaced intersecting cross sections by correlating boreholes and the outcrops-subcrops of units in order to produce a geological fence diagram of the area (fig. 2 A-C). Mathematical interpolation between the nodes along the sections and the limits of the units (outcrop plus subcrop) produces a solid model comprising a series of stacked triangulated objects corresponding to each of the geological units present (fig. 2 D-E). Once calculated, the block model can be analysed to solve problems as a decision support system (fig. 2 F-H).

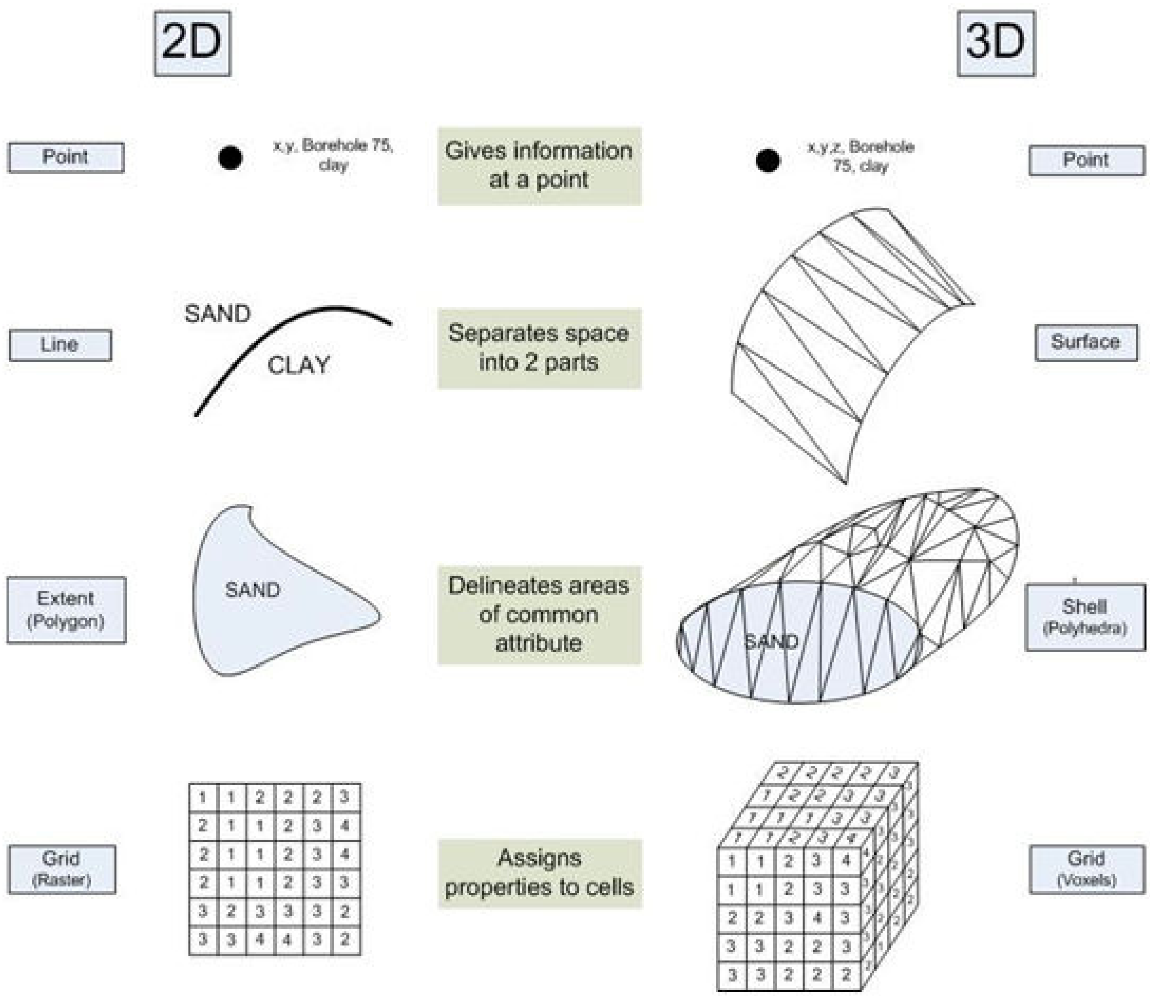

Figure 1. Data structures in 2D and 3D.

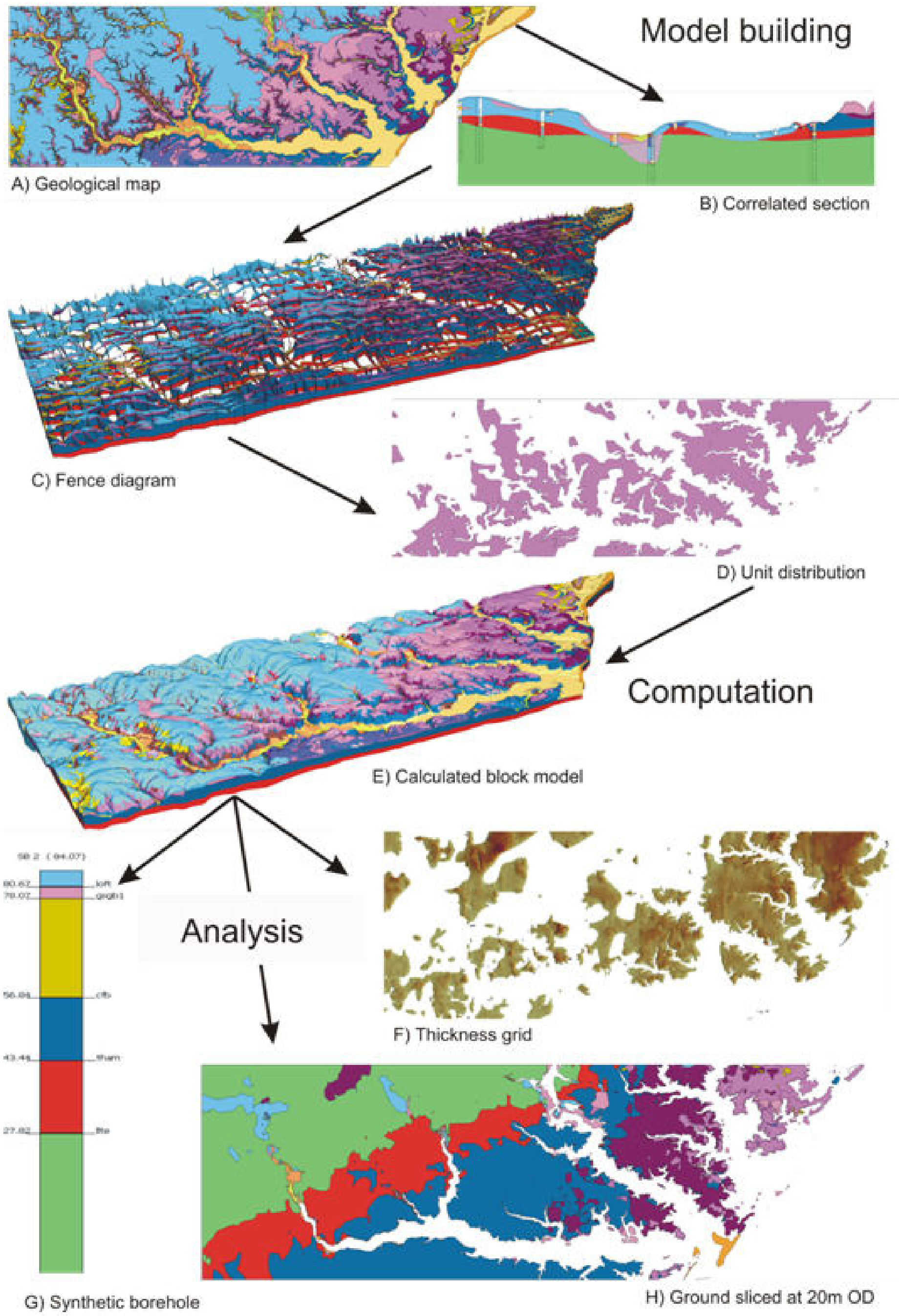

Figure 2. The GSI3D modelling workflow (from Kessler and others, 2009).

Discrete Process Models

A discrete process model simulates a particular process within the environment. For example, one of the most familiar of the Earth systems is the hydrological cycle (see figure 3). The cycle is made of a number of discrete processes that include:

- Rainfall
- Evaporation/Transpiration
- Unsaturated zone flow
- Groundwater flow.

Each of these processes can be modelled separately to gain an understanding of each element with the whole system, such as groundwater flow.

The BGS has developed groundwater models that more closely represent the structure of hydrogeological systems, producing flexible models that can both conform to aquifer geometry and simulate processes at different scales. In collaboration with the University of Birmingham and the Environment Agency, the BGS has developed the ZOOMQ3D (*http://www.bgs.ac.uk/science/3dmodelling/zoom.html*) as a discrete process model that is able to effectively model flow in a saturated groundwater system.

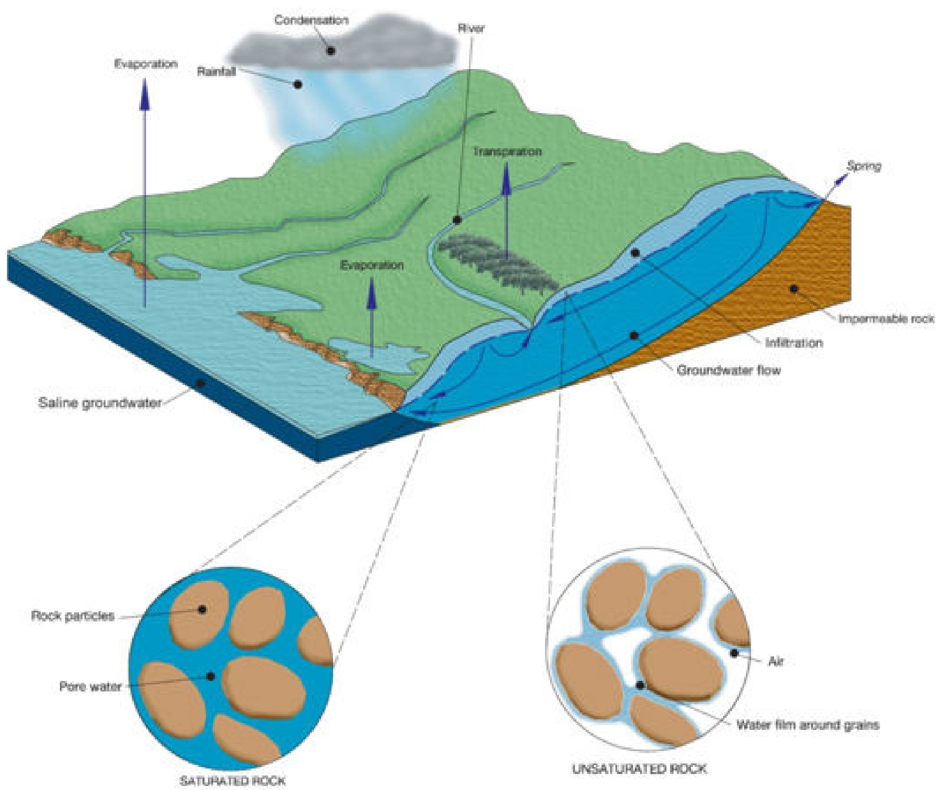

Figure 3. The Hydrological Cycle.

Linked Process Models

When a number of discrete processes have been successfully modelled, an expert can create new knowledge by taking the outputs of theses models and making an assessment of all or part of the whole system. In the case of water/groundwater, experts may make an assessment of groundwater recharge. To do this they may look at a climate model, a rainfall model, a catchment hydrological model, and a geological framework model.

Until recently it has been difficult to create a system to replicate what the expert does in the above process. The only realistic approach was to replace the existing models with a single new model that attempted to replicate the functions of the existing discrete process models. This has been a slow and expensive process that creates a further model that requires maintenance.

The alternative approach is to link two or more existing discrete models together at run-time so that they can pass parameters between each other. This effectively allows one model to query another model for a key parameter that it requires. This approach has a number of advantages:

- It is more cost effective,
- It is more agile, thereby allowing rapid development, and
- It allows the best of any existing models to be used and reused.

The Challenges the DAEM Project Faces

To achieve the vision, a range of challenges needs to be overcome. A DAEM Scoping Study Project has been established to report by end of March 2010 on the approach that will be adopted for each of these challenges in the implementation project. These challenges are:

- Software – Select the most appropriate software methodologies to achieve DAEM ambitions.
- Ontology and Semantics – The process of linking models also requires linking the concepts and classifications of those disciplines and the language used to describe them. To achieve DAEM goals requires ontological and semantic alignment.
- Scale – Environmental processes operate at scales ranging from microns to the scale of the solar system.
- Uncertainty – Understanding the uncertainties within a single model can be difficult. Understanding the uncertainties across a system of linked models represents a considerable challenge that must be addressed.
- Heterogeneity – Natural systems are heterogeneous, consisting of multiple components each of which may have considerable internal variation. Modelling Earth systems requires recognition of the inherent complexity.
- Data – Ready access to well managed data, in appropriate formats, associated with rich metadata, is essential for success.
- Intrusion – Any solution must leverage the investment in existing models rather than attempt to replace them.
- Standards – DAEM will have succeeded when its outcomes are recognised as formal international standards.
- Visualisation – Environmental models are most easily understood by their users when the output is an easy-to-interpret visualisation.
- Culture Change – DAEM must promote collaboration between researchers both within, and across, disciplines.
- Workflows – DAEM should reduce the chaotic nature of modelling of multidiscipline environmental issues and enable ordered, repeatable processes to be put in place.

These challenges are discussed in greater detail below.

Software

At the heart of the DAEM vision is the ambition to link existing environmental models together to gain a more complete understanding of the environment and the processes that occur within it. A number of systems exist that demonstrate that this is possible. For example, Caldwell and others (2009) reported a custom designed system. The work relates to the economically important Pacific salmon fisheries. The fish breed in the major rivers such as the Sacramento River of California. Competition for fresh water resources in California and climate change are affecting the survival of the juvenile fish. Their presentation entitled "An Integrated Framework for Improved Stream Temperature Predictions to Mitigate Fish Mortality" described a state-of-the-art modelling system with statistical analysis and prediction methods. The system allows a comprehensive set of decision support tools to be developed that will best guide water resource management decisions.

An alternative approach is offered by the OpenMI Association, which has produced an open standard for exchanging information between OpenMI-compliant models at run-time. The demonstration project, financed by the European Commission – Life Programme (*http://ec.europa.eu/environment/life/* and *http://www.openmi-life.org/*) is centred on the transnational Scheldt River Basin. Water management in the basin is distributed among many different authorities and operators in three countries: Belgium, France, and

Netherlands. Over recent years most of them have adopted modelling technologies to understand the hydrological/hydrogeological system that is under their responsibility. The introduction of the European Water Framework Directive requires water management to be integrated. Existing models have been developed independently, so integration is far from straightforward. The OpenMI Standard has provided an option that enables the existing models to work together. Four use cases were defined within the Scheldt Basin, in which various aspects of model linking will be tested. By the end of the project, it is hoped that water managers will have better insights into how interactions between water systems may affect strategic decisions (Devroede and others, 2008).

Ontology and Semantics

Ontology is the branch of metaphysics that deals with the nature of being (Oxford English Dictionary) whilst semantics is the branch of linguistics concerned with meaning (OED). These two subjects are closely related. Ontologies are used to define a real world object or concept, such as a mineral. For example, how do we distinguish a feldspar from other minerals, how do we distinguish a plagioclase feldspar from all other feldspars, and how do we distinguish a labradorite from all plagioclase feldspars? Semantics enable us to exchange information and knowledge about an object or concept that exist in an ontology. In environmental science, considerable effort is put into both the study of ontology and semantics. Within a particular scientific discipline there will have been a significant history of identifying objects, defining concepts, and developing the semantics to communicate information and knowledge about them. Within a particular scientific domain the level of common agreement on both ontologies and semantics should be high enough for humans to understand each other without too much confusion. It must be remembered that human communication relies on a wealth of domain knowledge in conjunction with inference skills. Clarification is sought by iterative questioning when doubt about meaning remains. Communications between computers currently are largely transactional. Information is requested and exchanged and there are simple, automated tests to ensure that transactions were completed as anticipated. However, there is little domain knowledge held by either computer in a transaction, neither of which has any significant inference ability, to verify that the transaction was both successful and that knowledge exchanged was correct (Reitsma and others, 2009).

The DAEM vision is to link together existing environmental models to gain a more complete understanding of the environment and the processes that occur within it. Linking models together requires more than a software solution. It requires a clear understanding of both the relationships between the concepts used within a given model and the mapping of those concepts into any models that are linked to it. This requires that the BGS has a mature understanding of the ontologies and semantics that it uses and has the ability to communicate these to others both in a human readable and machine readable format. It also requires that the BGS encourage its peer organisations to adopt the same approach.

The Web Ontology Language (OWL) is a language for processing Web information. It can be used to explicitly represent the meaning of terms in vocabularies and the relationships between those terms. This representation of terms and their interrelationships is called an ontology. OWL is designed for use by applications that need to process the content of information instead of just presenting information to humans. It has advanced facilities for expressing meaning and semantics and representing machine-interpretable content on the Web.

Scale

The environment is affected by processes that operate from the micron scale to the solar system scale and potentially beyond. Studies of aquifers polluted by dense non-aqueous phase liquid (DNAPL) have shown that a model of the behaviour of the pollutant within the pore spaces between the grains of the sedimentary material contributes to remediation of the polluted sites (Gooddy and others, 2002; Wealthall 2002). At the other end of the scale is space weather, which requires monitoring and modelling of the state of the space environment. It requires understanding of the behaviour of energetic particles as well as the changes in electric and magnetic fields. The main interest is in conditions in near-Earth space, though space weather is important throughout the solar system. The significance of space weather lies in its potential impact on manmade technologies on Earth and in space, for example, on satellites and spacecraft, electricity power grids, pipelines, radio and telephone communications, and on geophysical exploration.

Solutions that are developed during the DAEM Implementation Project must be able to handle the range of scales that are found in nature. The strap-line “*from pore to catchment and beyond*” well describes the requirement of the hydrological cycle, whose management is so critical to the well-being of an overcrowded island like Britain. There are two challenges relating to scale:

- Developing process models in heterogeneous environments where critical parameters may be at microscales and also at kilometre scales? For example, fluid flow in a rock body may be controlled by variations in pore throat diameter, measured at the micron scale, and changes in formation lithology may be measured at the kilometre scale.

- The uneven distribution of the available data, a common problem in geology. This leads to the requirement to ‘upscale’ and ‘downscale’

    - Upscaling is the problem of generalising from highly detailed local data to a more regional understanding.

- Downscaling is the reverse problem to upscaling, in which limited regional-scale information is leveraged to produce a more detailed local-scale understanding.

The challenge is to ensure that solutions produced by the DAEM Implementation Project take full account of the range of scales required in environmental modelling and are not restricted to only a limited scale range.

Uncertainty

All scientific models have associated uncertainties, whether such uncertainties are recognised by the modellers or not. The problem of uncertainties has long been recognised by statisticians and scientists (Chatfield, 1995).

Oreskes (2003) described the complexity paradox. As understanding increases, the natural reaction of any scientist is to add complexity to their models. In other words, as data are collected and understanding correspondingly improves, more and different processes can be added to any model. However, as more processes are added, the model requires more parameters, each with an associated uncertainty. Therefore, the overall uncertainty in the model increases. Oreskes described the paradox thus:

> *"..the attempt to make models capture the complexities of natural systems leads to a paradox: the more we strive for realism by incorporating as many as possible of the different processes and parameters that we believe to be operating in the system, the more difficult it is for us to know if our tests of the model are meaningful."*

So a more complex model better captures the nuances of the natural system, but it is more difficult to determine whether the model successfully reproduces the natural system. This has important implications for complex systems of linked models, such as those proposed for the DAEM Project. Whilst the overall system is better represented, there is an important issue as to how the modelling system can be tested against the observed response.

The uncertainties inherent in the linking of models are poorly understood and little research in the area has been undertaken. The limited numbers of models that have been linked together, to be used as predictive tools, seem to have avoided addressing the issue of the combined uncertainty.

It is the objective of the DAEM Project to link together framework and process models to produce a more complete understanding of the natural environment. Without a clear understanding of the uncertainties inherent in the combined models, the predictions they produce will have little credibility.

Research is being undertaken in this field. For example the GoCad Research Group, based at Nancy Universite in France, is becoming increasingly interested in uncertainty. Professor Caumon, Nancy Universite, recognises the success of 3D modelling and its growing importance as a major tool in natural resource management. However, it is important that modellers consider two other dimensions in their models, time and uncertainty. Geostatistical simulations have shown that one 'best' model is always limited in describing the reality and may lead to wrong predictions.

Heterogeneity

Natural systems are heterogeneous. This is often masked in small-scale models, which may be generalised. But for large-scale models there needs to be recognition of the inherent heterogeneity contained within them. The problem was articulated by Sivapalan and others (2003) in the International Association of Hydrological Sciences (IAHS) Science Plan.

Earth systems are made up of many individual processes that are related but which can vary independently. The variation may reflect natural cycles that may occur over a short time scale (for example, the season) or longer term (for example, orbital forcing and resulting climate change). Time-series data from observations of component processes within Earth systems may not fully capture the natural complexity because the duration of the observation may be inadequate. On top of this is the issue of human-induced change causing perturbations in time-series records, which increases the heterogeneity of these records.

The result of heterogeneity is to make the assessment of uncertainty more challenging.

Data

Well-managed data in the correct format with associated complete metadata are essential to the development of a comprehensive understanding of the natural environment. By well-managed we mean data that meet the eight dimensions of data management articulated by Feineman (1992). The eight dimensions are

- Accuracy
- Completeness
- Fidelity
- Lineage
- Quality
- Accessibility
- Security
- Timeliness.

These eight dimensions naturally fall into two groups. The first five dimensions reflect quality and the remainder refer to management.

Data Quality

High-quality datasets have exceptional completeness, accuracy, fidelity, and a clear lineage. The quality dimension is therefore a function of the dimensions of completeness, accuracy, fidelity, and lineage.

When users discover inaccuracies in a dataset they lose confidence in the data and in the data-management system in which it is stored. Effort should be made to ensure that the datasets are error free or that the error limits of the data are known, documented, and published.

Dataset catalogues can be frustrating when the datasets listed are missing or incomplete. For example a GIS dataset can be of limited value if it is missing its projection file. Completeness means all potentially available data are readily available on demand.

In the geosciences, many datasets are abstractions from the analogue originals. For example the majority of borehole logs are still transmitted as paper records, and a selection of the information is abstracted from the original for a specific purpose. The process of abstraction is potentially error prone. A dataset is described as having high fidelity when the digital representation of the information accurately reflects the original source.

Many datasets are processed a number of times before they are in a usable form. The history of the processing is known as the lineage of the dataset. A dataset has a good lineage when the original source of data is known, as well as details of all subsequent processes and transformations. Seismic reflection data are a good example. The original data collected in the field are processed through a number of steps to produce a dataset that can be studied by a seismic interpreter. At each stage of processing there are a number of values that can be assigned from a range of processing variables. To fully understand the dataset the interpreter may need to know the processing steps undertaken and the values assigned to the key variables. In other words, the interpreter needs to understand the entire lineage of the dataset.

Data Management

Well-managed datasets are those that are easily accessible, contain timely data, and are stored in a secure environment.

Scientists spend considerable amounts of time searching for and formatting datasets so that they are usable. Well-managed datasets are said to be accessible when the dataset is easy to locate and retrieve from a data store, they are available in the format in which it is normally used, and the intellectual property rights are clearly understood and articulated. Where the data volumes are large there must be adequate, rapidly accessible storage and high-speed access to the data store.

Such accessibility is predicated on good security. The datasets, and their related documentation, are protected from unauthorized access, inappropriate use, and partial or total loss.

Users become frustrated with datasets that do not contain the most up-to-date information. Such a dataset has poor timeliness. This is usually due to processing or inputting delays. Work-rounds are often implemented by users resulting in loss of control and multiple copies in use by the community. A timely dataset represents the current state of knowledge, or the state of knowledge at the time the data collection/synthesis is recorded and described.

Intrusion

Intrusion is an important concept in relationship to the DAEM Project. A single organisation will not succeed if it proposes an approach that assumes all other organisations will abandon their existing approaches, and the associated investments, and adopt the new approach. It would be too intrusive if the DAEM Project were to propose such an approach. The project team must respect the existing diversity of approaches.

The wonderful thing about environmental models is that there are so many of them to choose from.[2] Numerous environmental models have been produced to aid the study of various aspects of the natural environment. A study by the European Environment Agency (2008) produced a report called “Modelling Environmental Change in Europe: Towards a Model Inventory.” The report looked at more than 80 models that had been recently used in environmental assessments by the European Environment Agency. This is not an exhaustive list but gives an indication of the numbers of models that exist. These models represent a major investment in time and resources to produce and maintain. Individuals and teams have considerable intellectual capital invested in the models they have created and are reluctant to abandon their work and adopt an alternative model. The DAEM Project must not start from the assumption that it will develop new environmental modelling software that will replace the existing software. Such an intrusive approach into the existing environmental modelling community must be avoided.

The challenge is to ensure that solutions produced by the DAEM Implementation Project take into account the existing range of environmental models that exist and leverage the significant investment, rather than committing considerable resources into trying to replace well-established models.

Standards

A wide range of standards is applicable to the domain of environmental modelling. DAEM should not add to these unless absolutely necessary. The DAEM vision must be to adopt and support the development of existing standards rather than create standards that rival existing ones. Where new standards are required, these should be rapidly progressed

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[2] “*The wonderful thing about standards is that there are so many of them to choose from.*” Misquoting a statement attributed to Rear Admiral Grace Hopper

through to national and international standards. The adoption of this approach will reduce the potential conflict within the community and will reduce the risk of having to reengineer systems at some later date when one standard becomes dominant.

Visualisation

Environmental models are most easily understood by end-users when the output is an easy-to-interpret visualisation. To be successful in improving the understanding of environmental science and to provide knowledge to decisionmakers and policymakers, it is essential that DAEM outputs have clear visual interfaces that are simple to use.

An example of such a system is WaterSim (*http://watersim.asu.edu*). This is an Internet-based simulation of water supply and demand for the Phoenix metropolitan area that integrates information about climate, land use, population growth, and water policy. Adjustable settings allow the user to gage future water-supply conditions in response to climate change, drought, population growth, and technological innovation, as well as policy decisions about the nature of the region's built environment, landscaping practices, and recycled water. The systems and the science behind them still need well-written documentation at a range of levels from executive summaries to detailed user guides written for the non-specialist. WaterSim, for example, has extensive online documentation including:

- WaterSim Tutorial
- WaterSim Examples
- Teacher's Guide to WaterSim
- Students Handout for WaterSim.

It is clear that we need to learn lessons from existing environmental courseware about communicating science in an easily understandable way. Another example is the 'Carbon labs' in The Habitable Planet (*http://www.learner.org/courses/envsci/index.html*).

Culture Change

Individuals, small groups of researchers, or open communities develop and use environmental models. The majority of models are used by the individuals and research groups that develop them. Internationally recognized models such as MODFLOW (*http://www.modflow.com/*, a USGS-developed tool used by hydrogeologists to simulate the flow of groundwater through aquifers) are the exception. Few of the environmental models that are produced are designed to work with other environmental models. The majority are stand-alone systems that provide only a partial and incomplete picture of the environment. A study by Barkwith (2010) identified over 120 models in use within NERC.

The plethora of environmental models makes it difficult for non-specialists and for decisionmakers and policymakers to choose the appropriate models and to have confidence in the model results.

For DAEM to be successful there will need to be considerable collaboration, and promoting this change is one of the principal challenges for the project. It will require influencing research funders to promote collaboration in grant application and to recognize the important of transdisciplinary research. Communities that use large instruments, such as astronomers and high-energy physicists, have developed means of collaboration that recognize individual contribution whilst promoting collaboration.

Solution Workflows

Tackling multidiscipline environmental questions requires individuals or groups from each discipline to contribute information from their area of expertise. When all of the information is combined in the correct sequence, the resulting workflow contributes to the solution.

In practice the exchange of information is at times chaotic, often manual, time consuming, and poorly documented. It is difficult to reliably automate or audit such information flows without having agreed standards in place.

To produce a range of answers based upon a variety of scenarios often requires a significant amount of manual reprocessing. Each time a new scenario is modelled, there is a danger that the steps taken are inconsistent with previous model runs, leading to solutions or answers that cannot be reliably compared.

DAEM should encourage project leaders to consider up front not only which subject experts, data sources, and systems are required to provide an answer but also how information should be exchanged, and in which formats, and to formally document this in a workflow. Ideally the way a workflow is documented actually controls how system interfaces are defined.

Conclusion

BGS intends to put in place a framework that provides scientists with data, tools, techniques, and support to address transdisciplinary environmental questions impacting on human society. To achieve this goal, the DAEM Project was established as part of the BGS Strategy (2009). A scoping study was set up in 2009 to report early in 2010 on the challenges that have to be addressed and on the approach to be adopted. These challenges have been described above. We are confident that a suitable approach to addressing these challenges can be found. However, many of these challenges will only be solved by geological survey organisations and other environmental agencies working together to solve them. It is the aim of the BGS to create an open community that will share data, applications, techniques, and environmental models, thus enabling collaboration and achieving sustainable solutions. Clearly the BGS will not achieve such an ambitious vision on its own. Instead it intends to be part of a community and play a leading role within that community.

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The ESRI Geologic Mapping Template

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Introduction

An ArcGIS implementation of the Federal Geographic Data Committee (FGDC) Digital Cartographic Standard for Geologic Map Symbolization (“Standard”), the Geologic Mapping Template, provides a standardized set of the most commonly used geologic and supporting cartographic symbols.

The Standard developed out of the need to “support efficient production of geologic maps and related products, as well as to improve their consistency in both appearance and underlying database content.” Preparation of the Standard by the U.S. Geological Survey (USGS) on behalf of the FGDC began in the late 1990s, with the final publication released about 10 years later in August 2006 (FGDC, 2006; *http://ngmdb.usgs.gov/fgdc_gds/*).

The idea of the Geologic Mapping Template came to fruition in early 2009, but the work leading up to the template began a few years earlier. In late 2005, the USGS and ESRI began discussing the creation of symbols that met the complex specifications contained in the Standard. Cartographic Representations, a new functionality added to ArcGIS around this time, provided the means to produce the symbols that would meet those specifications. For 4 years, ESRI followed the guidance of the USGS and the Standard to develop over 1,000 of the 3,000 symbols in the Standard, focusing on the most frequently used symbols from Sections 1 – 18. By the time the development of the symbols neared completion, ESRI began publishing map templates, leading to the Geologic Mapping Template (GMT).

Map Templates

ESRI began publishing map templates in early 2009. The templates are designed as a resource for the ArcGIS user community, delivering a cartographic specification for a particular map purpose.

The templates typically consist of ArcGIS files, sample data, symbology, geoprocessing tools, documentation, and Web map applications when appropriate. They can be downloaded from the ArcGIS Resource Center Map Templates Gallery and saved on your local or network directory (fig. 1; *http://resources.esri.com/maptemplates/*).

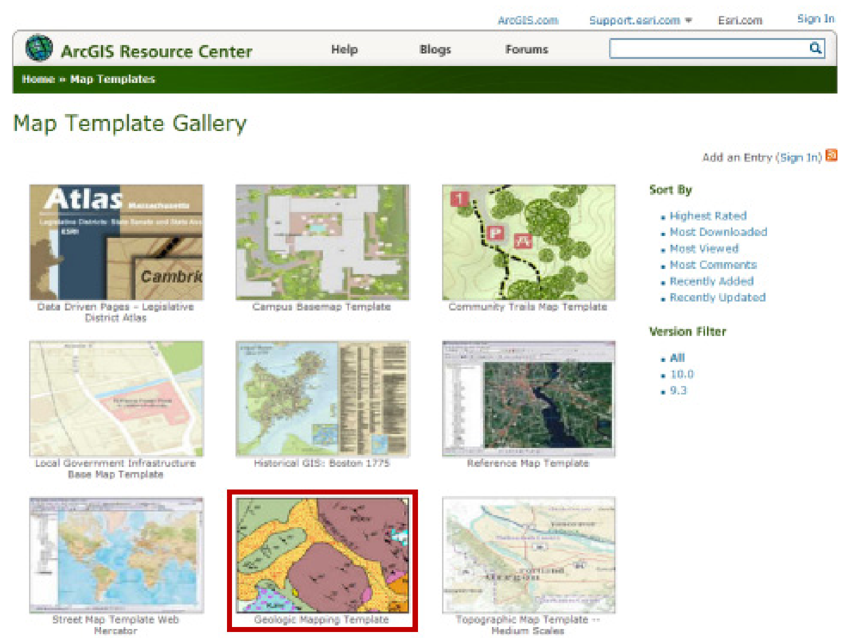

Figure 1. Map Template Gallery on the ArcGIS Resource Center. The Geologic Mapping Template .zip file can be downloaded from this site.

The Geologic Mapping Template

An ArcGIS 9.3.1 implementation of the Standard, the GMT is a complete solution for storing, managing, and symbolizing geologic map data. The Template contains a geodatabase with symbols and tools, a documented workflow, and an example map document and database with GIS data for the Geologic Map of the Mount Baker 30' x 60' Quadrangle by Tabor and others (2003) (fig. 2). It is available for download at *http://resources.esri.com/mapTemplates/index.cfm?fa=codeGalleryDetails&scriptID=16317*.

The example map and data-rich database demonstrates the result of taking data from the native format and pushing it through the 11 steps of the Getting Started document, included with the template. The template is scalable and flexible by design.

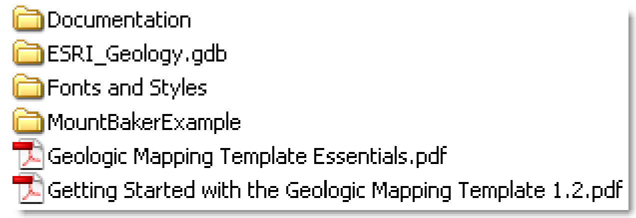

Figure 2. Contents of the Geologic Mapping Template (folder view) after the downloaded file has been unzipped.

Template Geodatabase

The GMT includes a geodatabase with a feature dataset, symbols, reference tables, and geoprocessing tools (fig. 3). The geodatabase schema is modeled after Appendix A of the FGDC Standard.

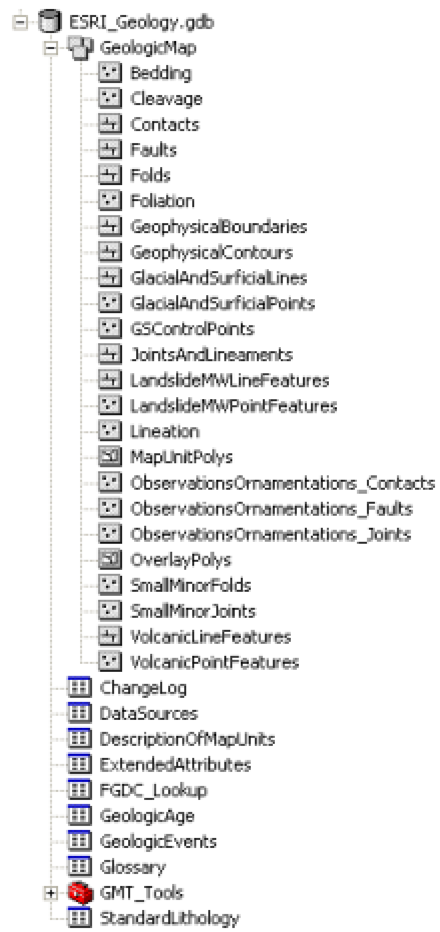

Figure 3. The Geologic Map Template file geodatabase.

Feature Dataset

The GeologicMap feature dataset contains 24 feature classes that are organized by the major symbol (representing feature) type classifications defined in Appendix A of the Standard, including:

1. Contacts, Key Beds, and Dikes
2. Faults
3. Boundaries Located by Geophysical Surveys
4. Lineaments and Joints
5. Folds
6. Bedding
7. Cleavage
8. Foliation
9. Lineation
10. Geophysical and Structure Contours
11. Fluvial and Glaciofluvial Features
12. Periglacial Features
13. Lacustrine and Marine Features
14. Eolian Features
15. Landslide and Mass-Wasting Features
16. Volcanic Features
17. Natural Resources

WGS84 is the defined geographic coordinate system for the template dataset.

Feature Class Representations (Symbols)

Each feature class in the GeologicMap dataset contains a corresponding set of symbols that is managed with what is known as a representation class. For example, the Faults feature class has a representation class that contains the symbols for the different types of faults, the Bedding feature class has a representation class that contains the symbols for the different types of bedding features, and so on.

Each representation class is composed of a set of rules, with a unique rule for each symbol. Each unique rule is given a unique identifier known as a Rule ID. Each rule also has a unique name. For the GMT, the rule name corresponds to the reference number (REF NO) for the symbol in the Standard (fig. 4). Cartographic Representations is the term that describes this entire symbol management system within the geodatabase.

The ability to store the symbology with the features in the geodatabase is essential for storing, managing, and sharing geologic map data. Whereas the traditional paper map represents a complete, interpretive geologic story, digital data only represent half of the story. A thrust fault representation, for example, has a complete and an incomplete story, depending on whether it is a symbol drawn on a map or is a feature in a geodatabase.

On a map, a thrust fault is represented by a line with little triangular-shaped teeth that repeat at regular intervals. The orientation of the teeth along the line indicates the direction of thrust. As data, a thrust fault is simply a line feature that has a ‘thrust fault’ attribution and unless the feature has been digitized following the right-hand rule as defined in the Standard, there is no guarantee that this feature will be properly represented when plotted in ArcMap. The teeth could plot on either side of the line representing the fault trace, or on both sides, offering an incoherent and inaccurate representation of the geologic feature (fig. 5).

The GMT offers a solution to bridge the gap between the data and its proper representation. Recall that the GMT is an ArcGIS implementation of the Standard. Therefore, the symbols follow the right-hand rule as defined in the Standard. Assuming the thrust fault has been digitized following the right-hand rule, the teeth will fall on the proper side of the line when it is symbolized with the thrust fault symbol in the GMT. However, if the feature was digitized following a convention that differs from the Standard’s right-hand rule, the feature may need to be flipped and (or) the symbol geometry edited to orient the teeth. Either way, the feature and symbol will be stored together in the database, assuring the data provider and the data user that the features will be properly symbolized when plotted in ArcMap.

For general information about cartographic representations, refer to ESRI’s online help on the topic that can be found on the Resource Center (*http://resources.esri.com*). For working with the representations in the GMT, refer to the Tips and Tricks section.

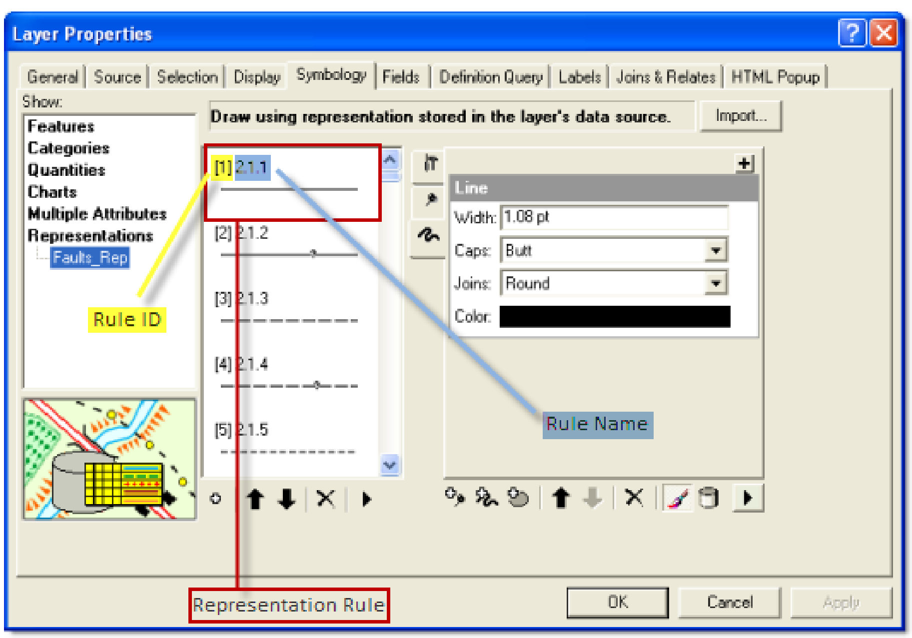

Figure 4. ArcMap Layer Properties Symbology view of cartographic representations.

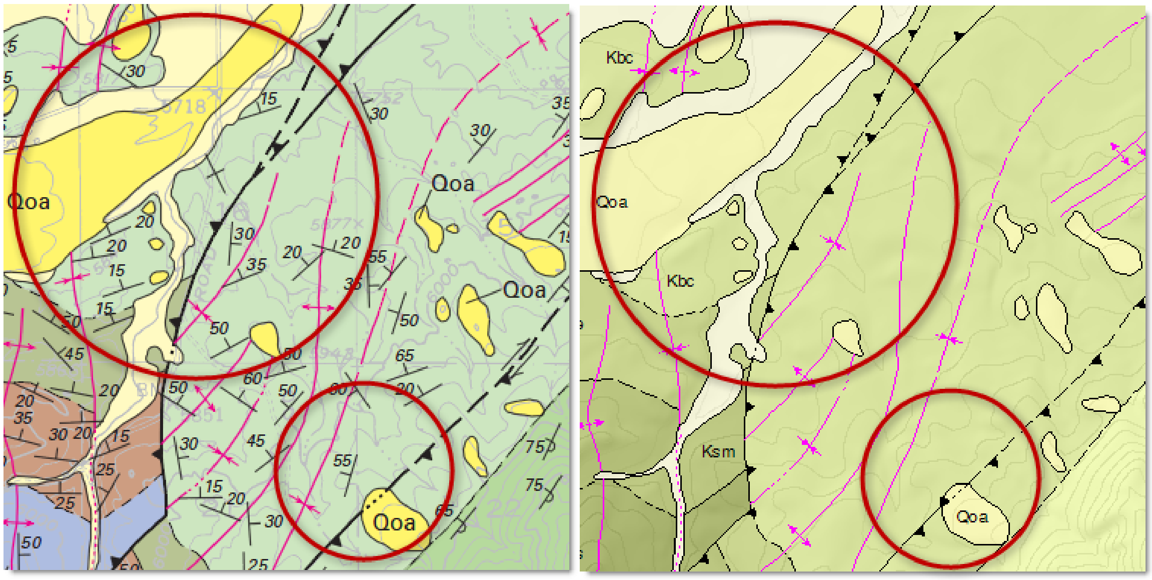

Figure 5. Comparison of thrust faults shown on printed map (to left) and symbolized from GIS data (to right). Map is the Sedan quadrangle, Gallatin and Park Counties, Montana (Skipp and others, 1999). Note incorrect symbolization from the GIS data.

Tables

The GMT geodatabase contains several tables. Some tables have no data but are designed to hold the supporting geologic information contained in your data, including data sources, description of map units, additional attributes, and standard lithology. The other tables include the GeologicAge table and the FGDC_Lookup table. The GeologicAge table holds the geologic age names and their age ranges, based on the Divisions of Geologic Time – Major Chronostratigraphic and Geochronologic Units (U.S. Geological Survey Geologic Names Committee, 2007) diagram. The FGDC_Lookup table (fig. 6) contains the symbols' reference numbers, symbol descriptions as defined in the Standard, and corresponding Rule ID values.

Toolbox

The tools in the GMT Tools toolbox (fig. 7) help bring everything together. The tools facilitate the creation of a project database with the appropriate projection, the migration of data from the native format into the project database, and the calculation of fields as described in the documented workflow.

Documentation

The GMT includes a set of documentation files that describe the structure of the template geodatabase schema, the sample map, and geodatabase contents, as well as a documented workflow.

Documented Workflow

The document "Getting Started with the GMT" outlines a step-by-step process for working with the template. "Geologic Mapping Template Essentials" serves as a companion document and provides more detailed information about the ArcGIS implementation of the standard, including an overview of the overall design of the template and an introduction to working with cartographic representations.

Example Map and Database

The complexity of the geology and the thoroughness of the publication "Geologic Map of the Mount Baker 30' x 60' Quadrangle" (Tabor and others, 2003; and fig. 8) proved to be an excellent example for testing the GMT. This became the example map and database that was released with the GMT.

For the GMT's example map and database, GIS data for the Mount Baker map were downloaded, and the 11 steps outlined in the Getting Started document were followed. One of the first steps in working with the template database is to project the GeologicMap dataset in the template database to match the local projection. In the Mount Baker case, the WGS84 geographic coordinate system had to be projected to Washington State Plane South. A tool is provided in the GMT toolbox to create a new database that follows the template geodatabase schema and a GeologicMap dataset that has a suitable projection for the mapped region (fig. 9).

RepRuleID	FGDC_REFNO	FGDC_DESC
1	1.1.1	Contact—Identity and existence certain, location accurate
2	1.1.2	Contact—Identity or existence questionable, location accurate
3	1.1.3	Contact—Identity and existence certain, location approximate
4	1.1.4	Contact—Identity or existence questionable, location approximate
5	1.1.5	Contact—Identity and existence certain, location inferred
6	1.1.6	Contact—Identity or existence questionable, location inferred
7	1.1.7	Contact—Identity and existence certain, location concealed
8	1.1.8	Contact—Identity or existence questionable, location concealed
9	1.1.9	Internal contact—Identity and existence certain, location accurate
10	1.1.10	Internal contact—Identity or existence questionable, location accurate

Figure 6. The FGDC_Lookup table.

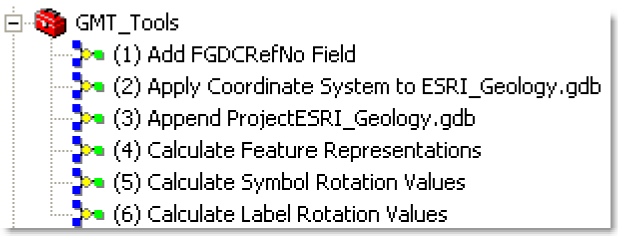

Figure 7. Geologic Mapping Template Tools.

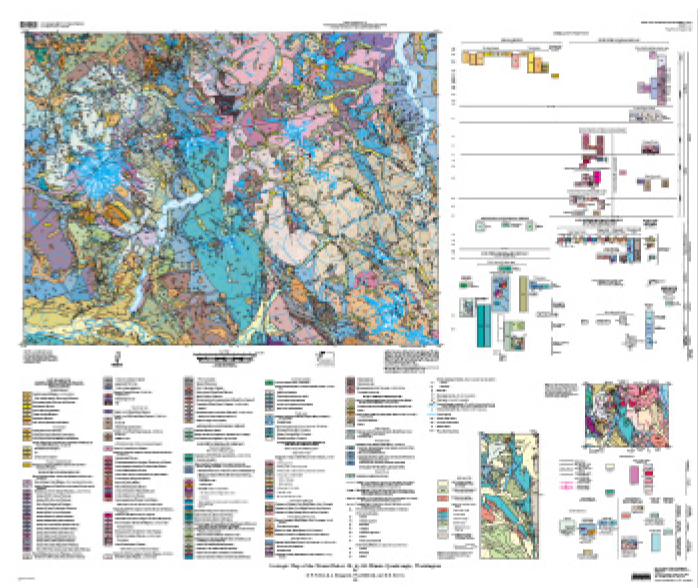

Figure 8. Image of the published Geologic Map of the Mount Baker 30′ x 60′ Quadrangle (Tabor and others, 2003).

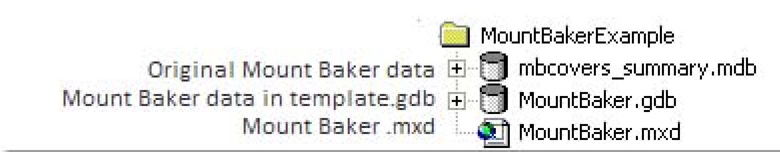

Figure 9. Mount Baker example map, reprojected in the Geologic Mapping Template.

Exceptions to the Rule

The GMT is designed to be flexible. If additional fields are needed to store additional data, simply add them to the feature classes in the template database. If additional feature classes are needed, add those to the template database. If you want to add cartographic representations from the template database to your own database schema, one option is to follow the steps below:

a. Load the "Faults" feature class from the "ESRI_Geology" (GMT folder) feature dataset into a new ArcMap document.
b. Open Layer Properties.
c. On the Symbology tab, select representations. Click 'Apply'.
d. Select, for example, the thrust fault symbol (2.8.1) .
e. Click the 'Rule Options' arrow below the symbol window.
f. Select 'Save Rule' (fig. 10).
g. In the "Save Rule to Style" window (fig. 11), make sure the symbol has a name and category. You can opt for the default or rename the symbol. For example, instead of naming it by the Reference Number (2.8.1 in this case), you can name it 'Thrust Fault, identity and existence certain, location accurate' to follow the convention of the Standard. The representation rule is saved to your personal style.
h. Repeat this procedure for each symbol/representation rule needed.
i. Add your existing feature class to a blank map document.
j. If they don't already exist, create representations. Right-click the layer and select 'Convert Symbology to Representation. . .' (fig. 12).
k. Right-click the layer (now with representations) and select 'Properties'.
l. Click the 'Rule Options' black arrow again and select 'Load Rule' (fig. 13).
m. Scroll through the symbol window (fig. 14) until you find the thrust fault symbol (2.8.1). Select the symbol and add the name of the symbol to the Rule ID field.
n. Repeat for each additional symbol.

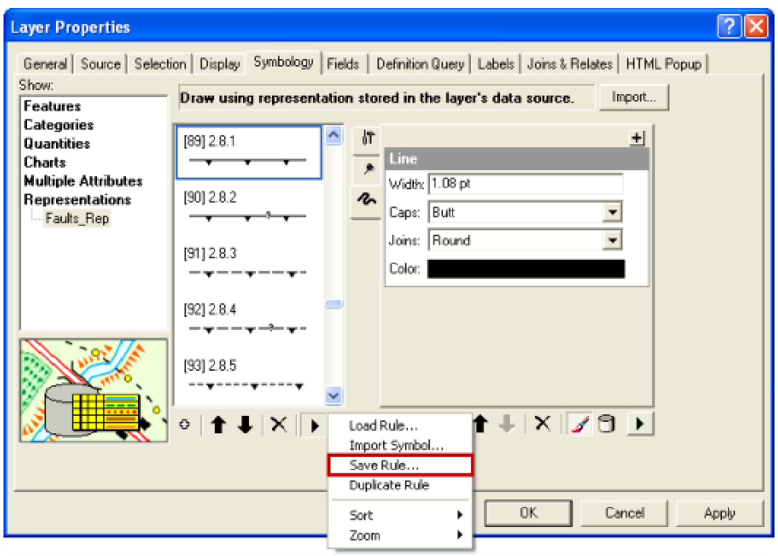

Figure 10. Saving a representation rule.

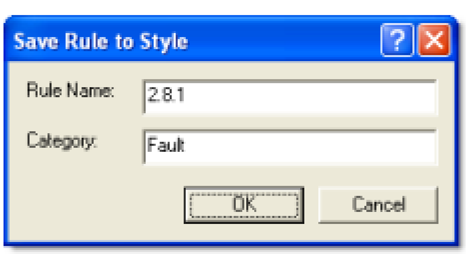

Figure 11. Naming and Categorizing a saved representation rule.

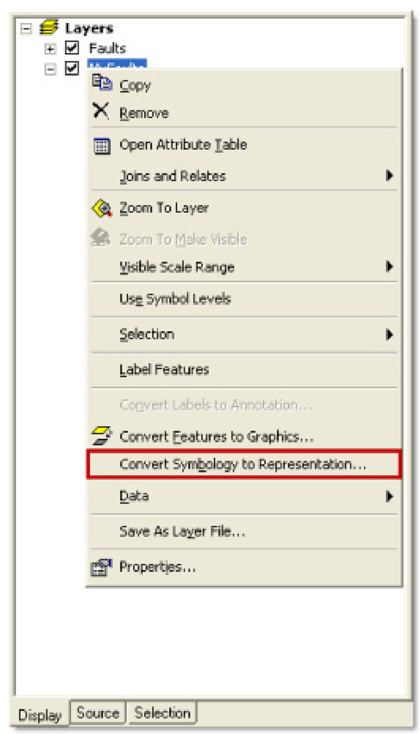

Figure 12. Converting symbology to representations.

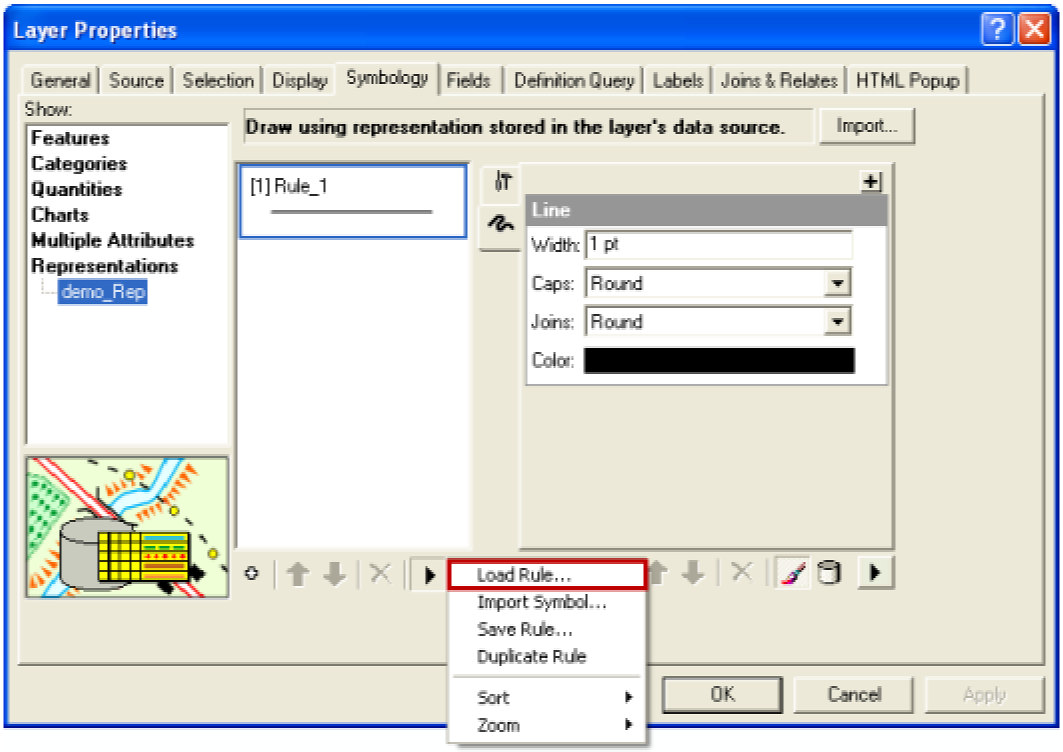

Figure 13. Loading a representation rule.

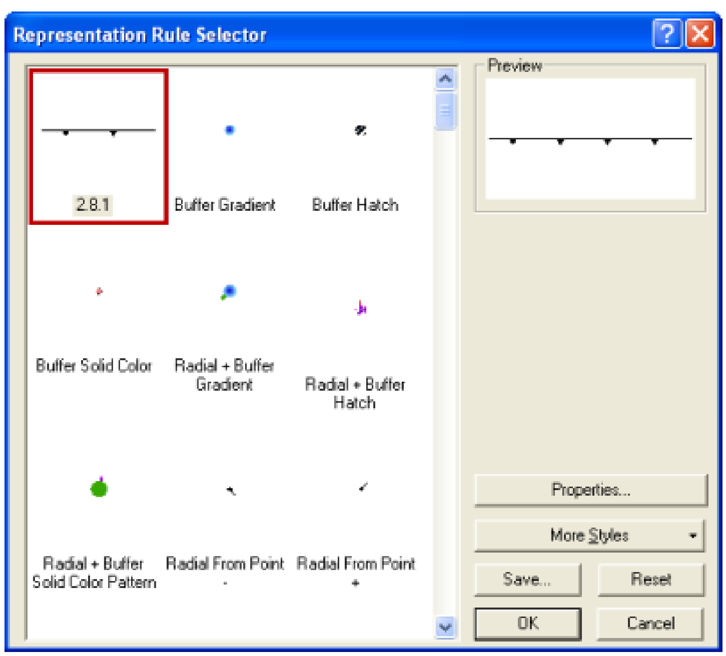

Figure 14. Selecting a saved representation rule.

Tips and Tricks

Cartographic representations are fairly new to ArcGIS Desktop, being released with ArcGIS 9.2. Since cartographic representation functionality differs from traditional methods of symbolizing features in ArcMap, this section offers three tips and tricks for working with cartographic representations efficiently in the template. The examples provided herein can be applied to any feature class.

Tip #1: Limit the number of symbols that draw in the ArcMap Table of Contents and in the map legend

The Faults feature class in the GMT, for example, has several hundred representation rules for each unique symbol type found under the Faults section of the Standard. However, only a subset of these symbols will be needed for any given map. Cartographic representations allow you to select the subset of symbols you would like to appear in the ArcMap Table of Contents and the map legend.

Under 'Legend Options' on the Layer Properties Symbology tab, select the subset of representation rules for the Table of Contents and map legend based on the symbols you need for a particular map (figs. 15 and 16). By selecting the two rules that will appear in the table of contents and in the map legend, these two rules are prioritized and appear at the top of the list in the Representations Layer Properties Symbology view (fig. 17). These rules are the only two rules that appear in ArcMap's Table of Contents (fig. 18).

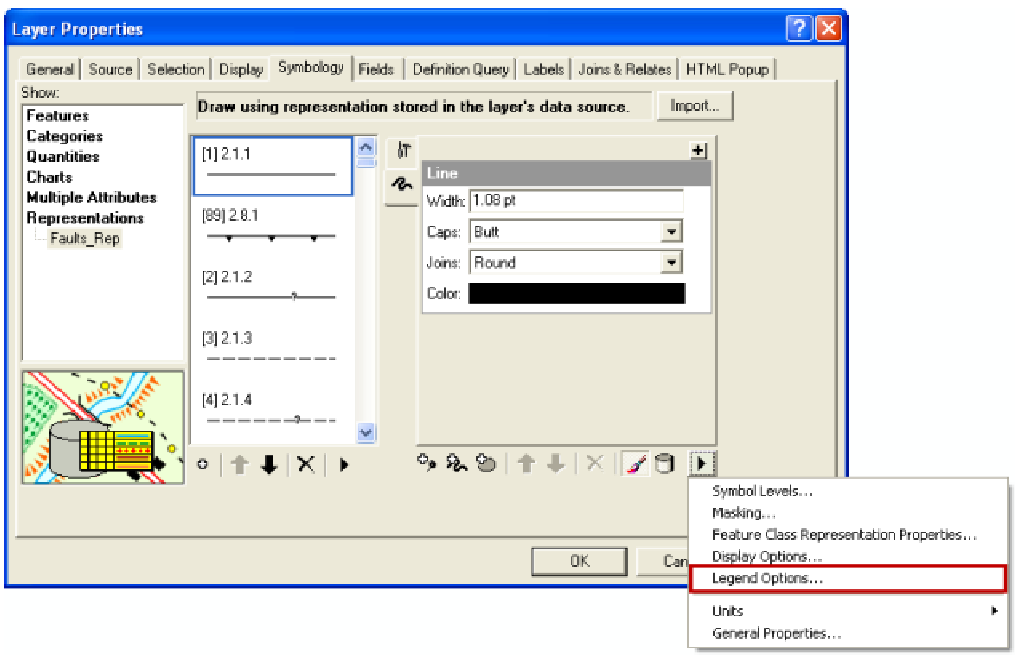

Figure 15. Navigating to Legend Options.

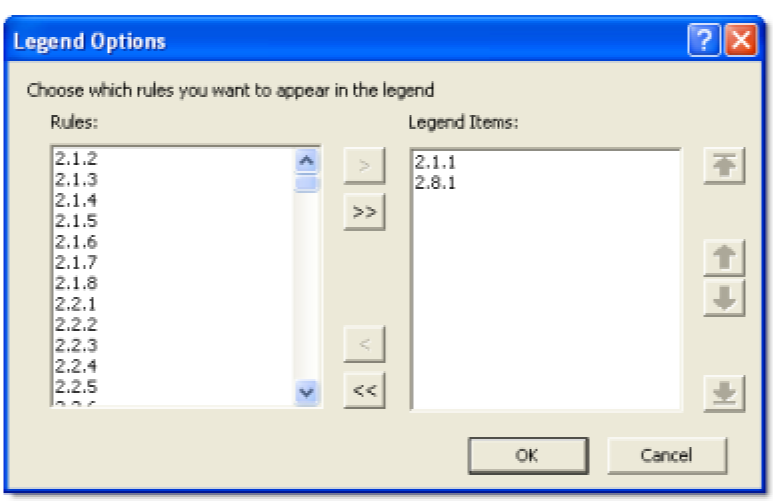

Figure 16. Selecting representation rules that will appear in the ArcMap Table of Contents and legend.

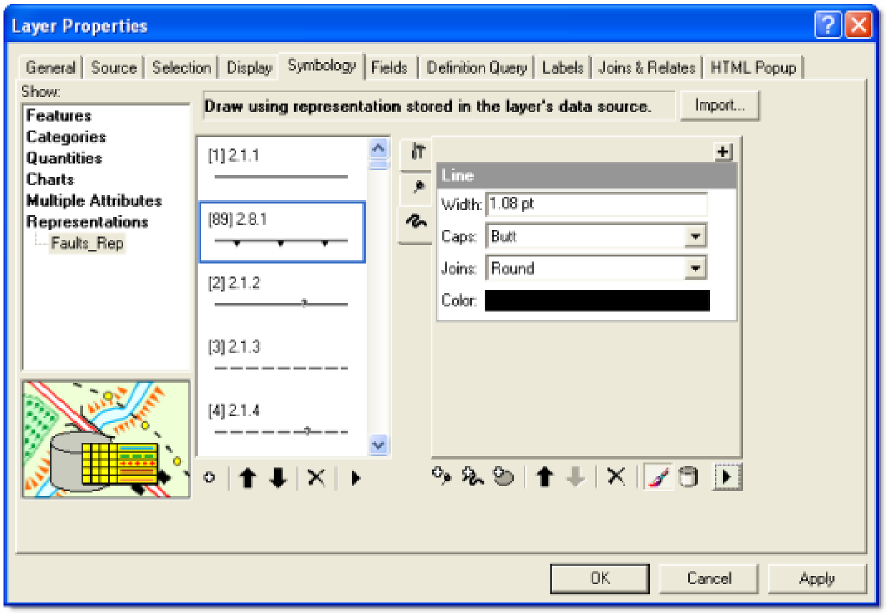

Figure 17. Selected legend items will move to the top of the representation symbology list.

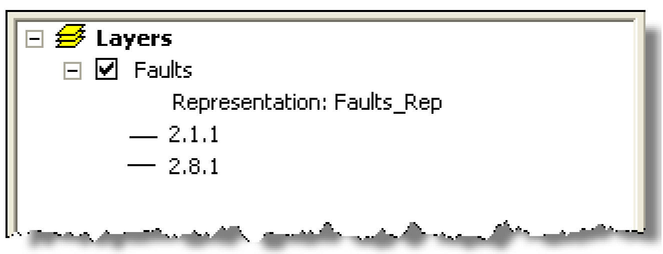

Figure 18. ArcMap Table of Contents view after setting the legend items.

Tip #2: Renaming representation rules

All of the symbols in the GMT are named by the Reference Number from the Standard. For example,"2.8.1" is the Reference Number that corresponds to the symbol representing a 'Thrust Fault, identity and existence certain, location accurate'. "2.8.1" is also the symbol name for Rule ID 89. However, this name can be changed. To change it, click in the field next to the Rule ID (the number in brackets, "[#]") on the Layer Properties Symbology tab and type a new name. You might replace the name with the full name, or a derivation of this name, something like 'Thrust fault - certain, accurate' (fig. 19). The new name will appear in the ArcMap Table of Contents (fig. 20) and in the map legend.

Tip #3: Keep data in the database without drawing the data in ArcMap

A scratch boundary is a good example of a feature that may be maintained in the database, but should not be symbolized on the map. With cartographic representations, this feature would be assigned a <null> Rule ID. When this layer is symbolized with representations in ArcMap, there is an option to not draw the feature, accessible through 'Display Options' on the Layer Properties Symbology tab (fig. 21). Uncheck the box next to "Draw representations that have an invalid or null Rule ID" to disable the drawing of those features (fig. 22).

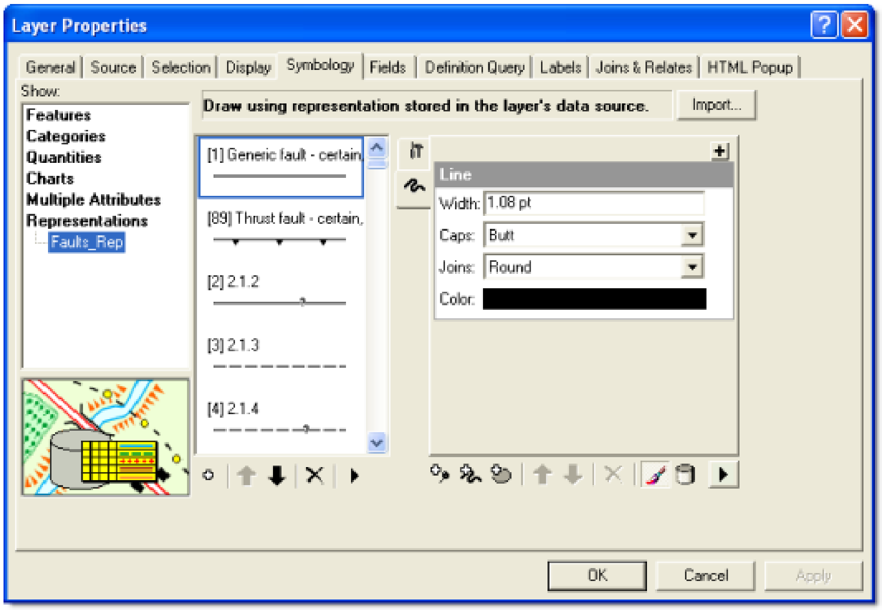

Figure 19. The representation rules, renamed.

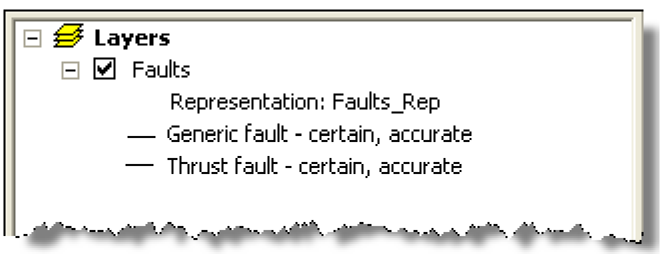

Figure 20. ArcMap Table of Contents view, after renaming the representation rules.

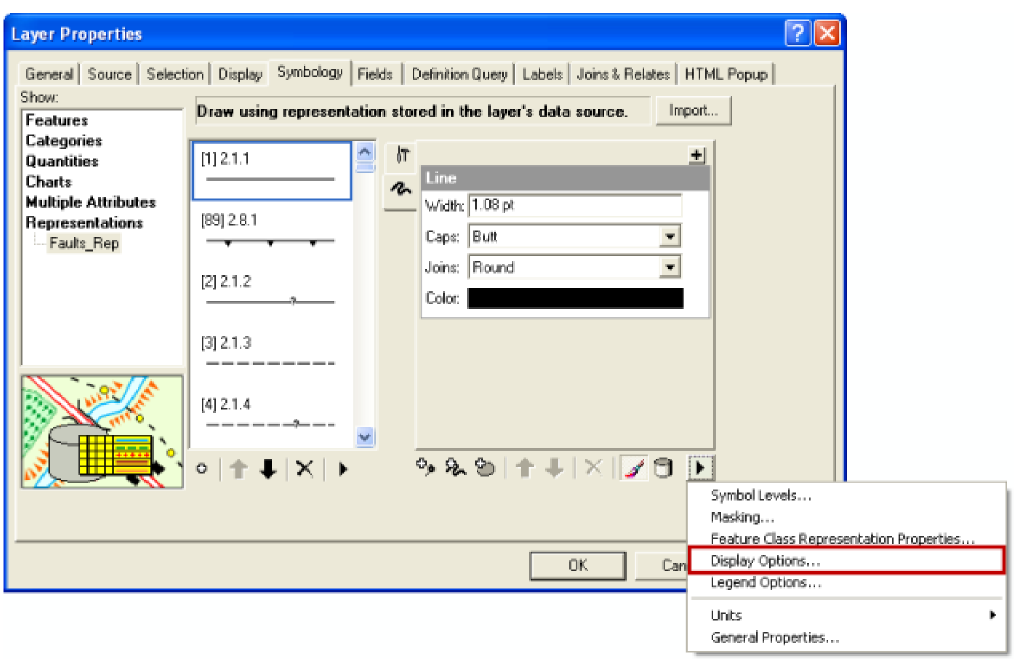

Figure 21. Navigating to Display Options.

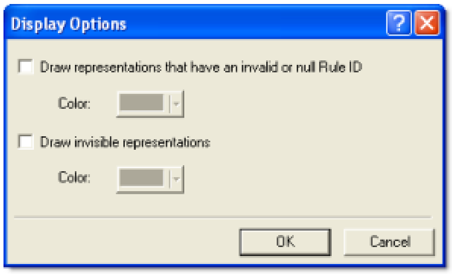

Figure 22. Unchecking box to draw representations.

Summary and Conclusion

The GMT is the first ESRI implementation of the FGDC Digital Cartographic Standard for Geologic Map Symbolization. It offers new opportunities and new challenges. For the first time, a standardized symbol set and documented workflow for creating a GIS-based geologic map exists, offering new opportunities in symbology continuity and the efficient production of geologic maps. Yet, there are still the obvious challenges associated with establishing new and appropriate workflows that take advantage of what the GMT offers and support existing mapping needs.

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NCGMP09—Draft Standard Format for Digital Publication of Geologic Maps, Version 1.1

By the USGS National Cooperative Geologic Mapping Program (NCGMP)

Prepared on behalf of the NCGMP by members of the National Geologic Map Database Project and the Pacific Northwest Geologic Mapping Project. Contributors (in alphabetical order): Ralph A. Haugerud, Stephen M. Richard, David R. Soller, and Evan E. Thoms
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NOTE: For the most current version of this document, and for further information including example database and tools, see http://ngmdb.usgs.gov/Info/standards/NCGMP09/.

Introduction

This document proposes a standard format for geologic map publications funded by the National Cooperative Geologic Mapping Program (NCGMP) of the U.S. Geological Survey. This format, or database design, is named NCGMP09 to reflect the initial audience. We hope that this design will adapt to evolving needs and expectations, and meet the needs of a larger community of users. NCGMP09 was introduced at the Digital Mapping Techniques '09 meeting (May 2009), as version 0.8.2, in order to solicit preliminary comments and testing. Version 1.0 was released October 14, 2009, for presentation at the Geological Society of America's Annual Meeting. In the months following, more extensive evaluations were received, and in response the design evolved. The document in these *Proceedings* reflects the current manifestation of NCGMP09 (version 1.1). For those readers interested in comparing earlier versions, these are archived at *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*. We and an extended group of colleagues will continue to revise the design based on comments received, and we intend to release a revised version under a new name in 2011.

NCGMP09 is a database design for encoding content analogous to that contained in a traditional geologic map published by the USGS and by State geological surveys. It stipulates an ESRI database format in order to adhere to USGS policy[1] and because this is the GIS most commonly used in the USGS, in the State geological surveys, and in the larger community. Migration to a nonproprietary format, such as the GML-based GeoSciML, is a worthy goal, and the database is designed with this in mind.

This design is intended to provide a stepping stone toward development of multimap databases, in particular the National Geologic Map Database (NGMDB). The NGMDB Project assists with coordination of database design work between the USGS and State geological surveys, and is mandated to build a national archive of standardized geologic map information. The database design proposed herein will significantly promote that goal.

In our years of work prior to defining NCGMP09, we learned that a single database design cannot (yet?) suit all purposes. This lesson has been underscored by our colleagues' evaluations of this design. A database most suited to the needs of a field geologist will likely not address the content and cartographic requirements of a single-map database that is intended to be published and then used by geologists and nongeologists, nor the requirements of a multimap database maintained in perpetuity by a mapping agency. We further recognize that even for one of these purposes a single design may be contentious, in part owing to varying requirements (for example, for field systems, requirements imposed by local geology or particular hardware). We have pragmatically developed a design that should prove generally useful, recognizing that many will not find it their first and best choice. Compromise in design, without sacrificing the flexibility necessary for science-driven information management, is the path we have sought during development of this standard.

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[1] General policy stated in Section 6.1.3 (USGS-only link at *http://geology.usgs.gov/usgs/policy/policy6.shtml*), supplemented May 24, 1999, by details shown at *http://ngmdb.usgs.gov/Info/standards/dataexch/USGSpolicy.html* (see section 3, but disregard reference to SDTS, which no longer is applicable).

Objective

Geologic mappers, geologic mapping agencies, and geologic map users would benefit from a standard database design for digital representation of geologic maps. This document proposes such a design for the representation of a single geologic map. The design is focused on the transfer and archiving of map data, with less emphasis on the creation of map data, the visual representation of map data, or the compilation of data from many maps. With increased use of this design we anticipate reductions in the cost of map production and publication (data compilation and synthesis, review, editing, cartography, pre-press, training, and tool development).

We focus on the representation of a single map for two reasons: this is the issue the geologic community (and our workgroup) understands best, and this is the problem that we perceive is most in need of a solution. The construction and maintenance of an enterprise, multimap database brings several issues that we do not here address, including versioning, multiple-scale representations, vocabulary management, maintenance of the stratigraphic lexicon, and access control.

For the purposes of this design, 'single geologic map' means a package of data (bearing in mind that many geologic 'data' are inherently interpretations) that pertains to a single portrayal of the geology of some area (the map extent), directly analogous to the traditional paper geologic map. While this package may include different views of the data—for example, the principal map view, one or more cross sections, perhaps one or more detail maps—each view is represented by a unique mapping between the data and symbols (graphical elements). As a publishable product similar to a conventional geologic map, the database package is attributed to an author or authors who have either collected original data and developed the data package and portrayal or have compiled data from existing sources and developed the portrayal.

This document is intended to bridge between geologic mapping and GIS communities at an operational level. We are codifying lessons from our experience and we expect that this document will be successful largely to the extent that it tells its readers what they already know.

Lessons Learned in the Last Two Decades

Geologic map data producers have been developing and using GIS representations of geologic maps for more than two decades. In the course of this effort we have all learned some lessons.

The distinction between map data and its symbolization is important. Maps can be represented digitally by scanning them and storing the image file, but this is a very small step towards making the map more useful and its constituent data more easily used for various purposes. Similarly, maps should be more than vector graphic files (for example, in Adobe Illustrator format). Map data are most usefully stored and analyzed in a geographic information system (GIS), with feature locations given in a real-world spatial reference framework (for example, UTM10, NAD83) and feature attributes stored explicitly in database tables (for example, line number 27 is an accurately located thrust fault, line 28 is an approximately located contact, line 29 is the shoreline of Lake Erie on Aug. 27, 1978). A map image, composed of lines, colored areas, patterns, and markers, is a symbolization of the data contained in the database, analogous to a tabular report based on financial data in an accounting database.

Maps need metadata for the overall dataset and for individual elements. Early GIS practices, largely stemming from limitations of storage space and database architecture, as well as paper-map precedent, led to the creation of a significant number of databases in which key fields were populated with symbols (for example, map unit = Ks) and these symbols were not defined within the database. This is inadequate. Most geologic maps have mixed origins and data qualities; map users benefit from feature-level metadata that describes data source and quality. Map data should be closely linked to authorship because maps are interpretations made by individuals or workgroups, and linked to sponsoring entities because most maps could not be made without significant support from a governmental agency, academic institution, professional society, or private industry.

Real-world database designs reflect compromises between the intrinsic complexity of geologic map data, the needs of geologists and GIS practitioners who work with the design, the capabilities of GIS and database software, and the limitations of the underlying computer operating system and hardware. Database designs that do not make such compromises are unlikely to be widely used. Even the names of data entities (for example, of spatial feature sets, tables, fields) must be carefully crafted to be readily understood by users with different backgrounds, to facilitate adaptation and re-use of software tools, and to promote distribution, translation, and compilation of data.

It is difficult to obtain community acceptance for data architecture (tables and spatial feature sets), data attributes, attribute names, and attribute vocabularies that extend beyond the precedents set by our paper mapping tradition. This conservatism is a good thing because our paper map tradition embodies a great deal of hard-won wisdom. But it is also unfortunate because our tradition reflects compromises necessitated by the limitations of the paper map format.

There is also a widely shared perception that paper geologic maps, with their subtleties of layout, sometimes carefully ambiguous descriptions, and textual and visual vocabularies that are often opaque to the uninitiated, are not readily used by the public that needs (and pays for) the information contained within these maps. We hope this proposed design contributes to a better understanding and wider use of geologic map data.

Acknowledgments

This database design is an outcome of years of research and collaboration by many scientists and GIS specialists, under auspices of numerous projects and initiatives. We gratefully acknowledge what we have learned from them, and hope this draft design sufficiently meets with their approval to warrant comment and improvement. In particular, we thank Peter Lyttle (Program Coordinator, National Cooperative Geologic Mapping Program) for his recommendation in 2008 that we undertake this work. We also thank our many colleagues who have given thoughtful comments and critiques of this design.

Contents

As an aid to comprehension, the content headings are provided here:

        - DataSources (non-spatial table)
        - Glossary (non-spatial table)
    - As-needed elements
        - Guidelines for naming and designing additional polygon, line, and point feature classes
        - Structure of point data
            - Point feature classes: general
        - Some examples of as-needed feature classes
            - OrientationPoints (point feature class)
            - GeochronPoints (point feature class)
            - Stations (point feature class)
            - GeologicLines (line feature class)
            - CartographicLines (line feature class)
            - IsoValueLines (line feature class)
            - OtherPolys (polygon feature class)
        - RepurposedSymbols (non-spatial table)
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        - Correlation of Map Units (feature dataset)
            - CMUMapUnitPolys (polygon feature class)
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            - CMUText (annotation feature class)
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        - ChangeLog (non-spatial table, optional)
    - Suggestions regarding workflow
        - Attributing ContactsAndFaults
        - Splitting lines to localize ornament (for example, bar-and-ball on normal fault) is bad practice
        - Building MapUnitPolys

  - DescriptionOfMapUnits table and DMU text
  - Formal metadata
  - Encoding additional information
- APPENDIX D. FREQUENTLY ASKED QUESTIONS

Review, Comment, and Revision

We seek a database design that has broad support from the geologic mapping community. Therefore, we ask that you review it and provide comment in order to, collectively, improve the database design, the documentation that explains it, and the tools and templates that facilitate its use. Please contact us via email, at *ncgmp09@flagmail.wr.usgs.gov*.

Regarding availability and maintenance of this database design, under the authority of the Geologic Mapping Act of 1992 (and subsequent reauthorizations), the National Geologic Map Database Project will function on behalf of the NCGMP as coordinator of database design changes and maintenance. This activity will be conducted in cooperation with NCGMP projects and other identified stakeholders (for example, the Association of American State Geologists).

Design Considerations

We have attempted to:

- Encode all the content of a traditional paper geologic map.
- Focus on the digital storage and transfer of a single geologic map. Facilitate interactive display and query. Provide a foundation for publication-quality visualization. Do not here try to solve the multimap database problem.
- Define the names and types of all constituent elements in order to meet user needs for consistency and to facilitate re-use of code and tools by map-producers. Use names that have obvious meaning to geologists and GIS practitioners alike.
- Address the persistent perception that traditional geologic maps do not meet the public's (and the scientist's) need for consistently named and defined earth materials data, by beginning to introduce standard terms and definitions, which may be extended in future revisions.
- Preserve, and facilitate the analysis of, map topology.
- Normalize map data for robustness and compactness of the database, but not to the extent that user comprehension is reduced.
- Allow queryable description of map features with as much (or as little) granularity as desired.
- For flexibility, interoperability, and data longevity, strive toward use of open file formats.

Content of a Traditional Geologic Map

Traditional geologic maps have rich semantic content that should be preserved in the digital publication. This content is outlined below. Yellow highlight denotes content for which we do not specify a digital form.

1. Map graphic
   a. Base map
   b. Map-unit polygons (polygons that cover the mapped area with no voids and no overlaps. May include open water, permanent snowfields and glaciers, and unmapped areas).
   c. Contacts and faults that, with a few exceptions, bound and separate map-unit polygons.
   d. Several elements that are present as needed to portray the content of a particular map:
      i. Overlay polygons, for example, alteration zones, perhaps extensive artificial fill, surface projection of mined-out areas. Note that while these polygons commonly represent features that are within, or beneath, the rocks and deposits represented by map-unit polygons, they are commonly represented on the map as patterned overlays.
      ii. Other lines, including traces of fold hinges, facies boundaries, isograds, cross-section lines, dikes and sills, marker beds, structure contours, and so on. In general, overlay polygons and other lines do not conform to the strict topological rules that constrain map-unit polygons and contacts and faults (no

polygon voids or overlaps, contacts lie on polygon boundaries, faults may dangle but contacts may not).

iii. Point data, which may include (but are not limited to) structural data (orientation measurements: axes and vectors), sample locations, geochronologic results, fossils, chemical analyses, prospect locations, displacement (fault-slip) measurements, and points for map-unit polygons too small to show at scale.

2. Zero to many cross sections (each with elements analogous to map elements, except that the base map is replaced by a topographic profile).
3. Correlation of Map Units diagram ("CMU") that includes unit designators, brackets, dividing lines, and text.
4. Symbolization for above, including:
    a. Map-unit area fills (color and optional pattern)
    b. Patterns for overlay polygons
    c. Line symbols and (or) point markers for map-unit areas too small to show as polygons at map scale
    d. Text tags for some (but not necessarily all) polygons
    e. Leaders for text tags for some polygons
    f. Line symbols (with variable color, weight, dot-dash pattern, repeated marker ornament, and so on) for some lines
    g. Text labels for some lines and groups of lines
    h. Point (marker and (or) text) ornaments for some linear features
    i. Markers and (or) text for some point data
    j. Leaders for markers and (or) text for some point data.
5. Description of Map Units (DMU) or List of Map Units with descriptions in an accompanying pamphlet. Traditionally, the DMU does not describe water, permanent snow and glaciers, unmapped area, and some overlays and underlays, but does include headings and some units not shown on the map (for example, Group or Formation which is entirely mapped as constituent sub-units). DMUs are strongly hierarchical. Each unit shown on the map has area-fill color and pattern, tag, unit name, age, description, position in hierarchy, and a paragraph style that (in part) denotes position in hierarchy. Headings and units not shown on the map lack area fill color and pattern and tag.
6. Explanation of line symbols
7. Explanation of point symbols
8. Miscellaneous map collar material. Includes report title, author(s), date of publication, publisher, series and series number, mapped-by statement, edited-by statement, cartography-by statement, specification of spatial reference framework, and scale.
9. Zero to many figures
10. Zero to many tables
11. Zero to many additional maps (for example, sources of map data; distribution of facies in the Cambrian)
12. Extended text, as needed
13. References Cited, as needed.

Extensions to Traditional Geologic Map Content

We include several extensions to traditional geologic map content. Three are required: feature-level metadata, an internal dictionary that replaces some of the detailed descriptions of entities and attributes in report-level metadata, and categorization of map-unit lithology using a standard scheme. Optional extensions are supplemental standardized lithologic descriptions of map units, extended attributes to add additional properties, and structured, more detailed descriptions of the ages of geologic events; these may be used to store content that otherwise might be stored in extended text, tables, or figures.

Feature-level metadata

All elements of a geologic map database should be accompanied by an explicit record of the data source. Many elements should also have explicit statements of scientific confidence—for example, how confident is the author that a feature exists? Or that it is correctly identified? How confidently are feature attributes known? These are challenging questions to which the field geologist may not be comfortable providing an answer, except in the most general sense. We recognize this. But we also recognize that geologic information commonly is used in a GIS, in conjunction with other types of information (for example, cadastral surveys, road networks, pipelines), and that terms such as "accurately located" have a markedly different meaning for a pipeline or property line than for a geologic contact. Thus in order to provide a general indication of the confidence and locational accuracy of geologic-map features, we implement per-feature descriptions of scientific confidence and locational accuracy. For more discussion of this topic, please see Section 4 of the FGDC Digital Cartographic Standard for Geologic Map Symbolization, FGDC-STD-013-2006, *http://ngmdb.usgs.gov/fgdc_gds/*.

In some cases, default confidence and locational accuracy values for an entire map are appropriate. Although default values may seem meaningless, changes in default values from map to adjacent maps are likely to be informative to map users. As software tools evolve, we expect to see changing work flows that produce more detailed metadata.

Data source (provenance). Typically, a single map database will have very few data source records, as many features will have identical sources. For a database composed entirely of new mapping, there could be a single data source: "this report". Some data elements have compound sources: geochemical analysis of a rock sample will typically have one source for the map location and stratigraphic provenance of the sample (the field geologist) and another source for the chemical analysis (the geochemist). In such cases, multiple source fields in the relevant data table are appropriate, for example, LocationSource and AnalysisSource.

Location confidence (spatial accuracy). Reported locations of geologic features commonly are uncertain. This may be because of error in locating observation points (because of, for example, GPS error or an imprecise base map), or because features are subtle and difficult to locate, or because the locations of features are known by inference from the locations of other observations. Such uncertainty could be expressed as uncertainty in absolute location (that is, geodetic accuracy). However, because most users locate geologic features in relation to an associated base map, and because most spatial analyses of geologic map data are in relation to the base map or to other data in the same database, we choose to focus on location confidence relative to features on the base map and to other data in the geodatabase. We define location confidence (database field LocationConfidenceMeters) as the combination of error in positioning of observed features or known positions relative to the base map and the uncertainty in location of a feature relative to a known position (that is, how precisely, relative to where I am standing, can this contact be placed?). For a well-exposed sharp contact, the second factor is zero and location confidence becomes equivalent to positioning error.

This usage differs from that advocated by section 4.2 of the FGDC standard, which suggests that spatial accuracy be expressed as three attributes: (1) locatability (with values of *observable*, *inferred*, or *concealed*); (2) zone of confidence (a distance, perhaps equivalent to 1/25th of an inch at map scale; may be the same for all parts of a map or may vary spatially); and (3) positioning (with values of *within zone of confidence* or *may not be within zone of confidence*). We depart from the FGDC recommendation in order to create databases that are less dependent upon visualization scale, more informative (if a feature is not positioned within the zone of confidence, the FGDC recommendation provides no way to record any quantitative knowledge of how well located the feature is), simpler, and more comprehensible.

LocationConfidenceMeters should be reported as the estimated radius (in meters) of the circle of uncertainty about a point location, or the half-width (in meters) of the zone within which a line is asserted to be located. Values commonly will not be known precisely. This is acceptable. Even with a factor-of-two uncertainty, author-assigned values of LocationConfidenceMeters are preferable to an unreported value or a value assigned by a third party. The positions of certain lines (for example, map boundaries) commonly are calculated, not observed; for these lines, positional uncertainty has little meaning and LocationConfidenceMeters should be assigned a value of 0.0. For some digital transcriptions of legacy paper geologic maps, it may not be possible for the transcriber to assign an approximate value to LocationConfidenceMeters. In these cases, a negative value (for example, -9) may be used to indicate "unspecified."

Existence confidence, identity confidence, and scientific confidence. The FGDC Standard notes that scientific confidence may have multiple dimensions. For a map-unit area, scientific confidence has one dimension: confidence that the map unit is correctly identified. In the case of faults, contacts, and other feature traces, the situation is more complex. There may be uncertainty as to whether a boundary between two units is a contact or fault. There may be uncertainty as to what kind of fault is mapped. In both cases, this uncertainty is specified by an identity confidence value. In some cases, the presence of a fault may be suspected but is not certain. Fold hinge surface traces, dikes, and marker beds may also be mapped where their existence is suspected but not certain. This uncertainty is specified by existence confidence. Contacts are rarely mapped where their existence is uncertain; if different map units are identified, there must be a boundary of some sort between them, in which case the identity of that boundary may be questionable, but not its existence.

NCGMP09 includes ExistenceConfidence and IdentityConfidence for line feature classes, and IdentityConfidence for polygon and point observation features. We discussed at length whether to combine these confidence concepts into a single ScientificConfidence field in the database, perhaps with 4 or 6 values to allow for various combinations of existence and identity confidence, but decided that it makes more sense to leave both as separate fields, as specified in the FGDC Standard. We expect that symbolization will in some cases be assigned on the basis of feature type and the appropriate confidence terms. As noted above, in many situations default values for the entire map area are appropriate; in situations, tools to efficiently assign confidence values can be developed.

For most databases we expect that all ExistenceConfidence and IdentityConfidence values will be either "certain" or "questionable," though this Standard allows other values (which must be defined). For some digital transcriptions of legacy paper geologic maps, it may not be possible for the transcriber to assign values of ExistenceConfidence or IdentityConfidence, and these may be coded as "unspecified." Appearance of such values in a database of new mapping should raise a red flag during the review process.

Orientation confidence. For measurements of rock structures (bedding, foliation, lineation, joints, and so on) it is useful to describe how accurately the orientation has been measured. This is specified as the circular error of a direction (for planar features, of the pole to the plane), which is most usefully expressed as an angular measure (of the radius of the error circle) similar to the $alpha_{95}$ value often reported for paleomagnetic directions. The OrientationPoints feature class includes an OrientationConfidenceDegrees field to record this uncertainty.

Glossary

Many digital geologic map databases (and many published paper geologic maps) have provided definitions for few, if any, of the technical terms used to name and describe map features. A few producers of geologic map databases have remedied this with formal metadata that contains definitions and definition sources for elements of enumerated value domains within detailed entity and attribute descriptions. Such definitions and definition sources, unfortunately, can be difficult to access and nearly impossible to relate automatically to the relevant features in the database. We implement a Glossary table that, for certain fields, lists the terms that populate these fields, term definitions, and sources for definitions. Definitions and definition sources are readily accessed with a standard relate based on the term field. Formal metadata, in the overview description of a feature class or table, could reference the Glossary table for definitions and definition sources; listing of definitions and sources within detailed entity and attribute descriptions is not necessary.

Terminology used in the database must be defined in this Glossary. If this seems excessively laborious, consider that if terms are defined in this Glossary they (1) are more readily available for display on-screen within the map; (2) can be more easily searched and extracted for other publications; and (3) can be used as sources for data-driven products such as metadata.

Creation of the Glossary table should not be an undue burden on the database producer. In most cases, definitions copied or paraphrased from standard sources (for example, AGI Glossary of Geology, with appropriate attribution) will be appropriate. Terms used only in the Description field of the DescriptionOfMapUnits table (defined below) need not be defined. 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 to develop, as a prior Glossary can be recycled with minor amendments and updated DefinitionSourceIDs.

General Lithology

The traditional Description of Map Units conveys essential information about each map unit. As such, it is a cornerstone of the NCGMP09 design. However, these descriptions vary in their content and format and commonly use specialized terminology that is unfamiliar to the nongeologist. Terminology may, for valid reasons, be used inconsistently from map to map. For these and other reasons, many classifications have been devised in attempts to organize and standardize descriptions of geologic map units, improve our ability to make regional compilation maps, and better convey geologic information to the public. Of necessity such classifications are compromises that only partially describe the near-infinity of map-unit compositions, textures, genesis, and appearance.

The North American Data Model Steering Committee (*http://nadm-geo.org/*), sponsored by USGS, AASG, and the Geological Survey of Canada, defined a general, conceptual data model for geologic maps and a "Science Language" for describing various characteristics of earth materials. The summary report on science language is available at *http://pubs.usgs.gov/of/2004/1451/nadm/index.html*. The classifications presented in that report have been evaluated and adapted for many purposes; for example, the IUGS-CGI Geoscience Concept Definitions Working Group has incorporated that work into a limited set of lithology categories ("SimpleLithology") for use in GeoSciML interchange documents (see *https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG*).

A similar list of terms, known as "StandardLithology" accompanied the initial release of NCGMP09 (version 1.0). The StandardLithology term list and GeoSciML's SimpleLithology were designed to be used with a ProportionTerm list to encode the numerous lithologies found in each map unit and their relative proportions. This approach encourages multiple entries for each map unit, thereby allowing description of map units in some detail. StandardLithology was received with little enthusiasm by many of the reviewers of version 1.0.

We remain convinced that standardized map-unit descriptions are beneficial, largely because of their potential to:

1) Facilitate queries for the presence of a particular rock type. Using a hierarchical classification, both the queried rock type and all rocks related to it can be found (for example, if "volcanic rock" is queried, "basalt" also is returned).
2) Allow more-uniform portrayal of lithology across multiple maps.

3) Focus the geologic-mapping community on the generally held notion that standard classifications are useful. What should these classifications contain, and what is their purpose?

Bearing in mind the importance of giving the public a simple and systematic view of the Nation's geology, we include in NCGMP09 a simplified classification based on general lithologic and genetic character. This classification, GeneralLithology, applies a single term to each map unit, providing information that a non-expert can quickly use to identify map units that contain similar materials. We recognize that from the field geologist's perspective a single standard classification cannot adequately address the geology of a given region in sufficient detail. Therefore, we also encourage more detailed descriptions of the distinct geologic materials that occur within map units using the optional StandardLithology table, as described in Appendix B.

The GeneralLithology term list now included in NCGMP09 was developed for the NGMDB Data Portal, a prototype site (ca. 2008) intended to raise discussion with NGMDB partners in the State geological surveys regarding how to provide the public with an integrated view of regional-scale geologic maps, with links to the source map information. The term list and associated confidence terms are given in Appendix A. Documentation of the term list, including rationale, is provided in Soller (2009; *http://pubs.usgs.gov/of/2009/1298/pdf/usgs_of2009-1298_soller4.pdf*).

Is GeneralLithology (and StandardLithology as well) adequate and appropriate for the intended use? As implied in item 3 above, the process of developing such lists is iterative: although the community has already devoted significant effort to standardizing terminology for map-unit lithology, this work needs to continue. Discussion will be most effective after a term list has been evaluated by application to geologic map databases that are being prepared for publication. It is important to bear in mind that the NCMGP09 database is focused on data delivery to the public. Scientists engaged in geologic field research may wish to have more detailed, structured terminology in their research databases than is possible with the NCGMP09 schema or the GeneralLithology and StandardLithology vocabularies. For those scientists and their mapping projects, evaluation of the salary and programming costs versus the research and societal benefits of implementing supplemental data structures and vocabularies may indicate that the NCGMP09 schema should be extended in order to create more precisely constrained, controlled-term descriptors. If this is found necessary, please refer to the method noted for StandardLithology, in Appendix B.

We anticipate that evaluation by map producers (that is, geologists) and end users will cause the NCGMP09 terminology lists to be revised. Revisions will be posted to *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*. We will solicit comments in group discussions (for example, with mapping projects and agencies, and at Digital Mapping Techniques meetings). We also request that individuals send comments to us at *ncgmp09@flagmail.wr.usgs.gov*. Of immediate concern are: What specific difficulties have been encountered in attributing map units with GeneralLithology? How does the term list need to be revised? In the longer term, comments on effectiveness of these controlled-term lists for geologic analyses, or compilation efforts, also are welcomed. Please bear in mind that GeneralLithology is not intended to supplant more detailed and precise lithologic terminology used in the Description of Map Units text or in more detailed and specialized controlled-term lists.

Naming Database Elements

Fixed, easy-to-comprehend names for all elements are key to a functional geodatabase design. Names have been chosen according to the following criteria:

- Names convey content to the geoscientist, to the GIS practitioner, and to the public
- Names use uniform concatenation protocol (CamelCase, the first letter of each word is in upper case)
- Names do not exploit case sensitivity. Note that case should be conserved, as some languages and operating systems distinguish between *ThisName* and *thisName*
- Names do not contain spaces or special characters
- Long names are acceptable and informative
- Names are easy to code and calculate
- Names reflect data type
- Names point to related tables. Field names which contain "SourceID" are reserved for foreign keys to table DataSources
- Field names which contain "_ID" are reserved for primary keys. These are of the form *TableName_ID* or *FeatureClassName_ID.* These primary keys are maintained by the database creator, not the GIS software, and are used mostly to relate attributes stored in non-spatial tables to spatial features, and—optionally—to relate spatial features to additional, feature-specific attributes stored in tables ExtendedAttributes and GeologicEvents.

We have chosen not to encode the publication identity (map name or map series number) in the names of feature datasets and feature classes. Feature dataset and feature class names that include a map identifier (name or series number) would simplify the joint display of multiple publications in an ArcMap project because each layer name automatically includes the map identifier for the layer. Our choice to use the same name for feature datasets and feature classes in all delivery databases keeps the naming scheme simple and facilitates the coding and sharing of tools to manipulate geodatabases. Users who create ArcMap projects that reference multiple databases may find it convenient to manually update the names of layers to reflect their map sources.

Transparent Identifiers

Identifiers in the database for map units, line types, and point feature types should have obvious plain-English meaning. The map-unit identifier is used as a foreign key from the DMU table to various other tables, and this should be the unique label used to identify that unit in map displays. Entries in the DMU that are not symbolized on the map may have null map-unit identifier values. The type identifiers for lines and points are references to terms in the Glossary, and we recommend that these simply be the geologic term for the line or point type represented. This is in contrast to common practice which dictates that identifiers used as foreign keys in a database are best implemented as numbers or text string that have no inherent meaning to users; these commonly are referred to as opaque identifiers. Though opaque identifiers may be more robust, we think that for a delivery database this advantage is outweighed by the greater intelligibility for people gained by using human-interpretable identifiers. Note that this specification does not prohibit the use of opaque identifiers, particularly for primary key (table_ID) values.

Open File Formats

In principle, we encourage the use of open file formats, because: (1) open formats facilitate writing and redistribution of third-party code; (2) open formats reduce the risk of locking data up in formats that become obsolete and unreadable – when open formats are superseded, documentation for them is likely to remain available; and (3) open formats are likely to change in a more measured fashion than proprietary formats. Many in the geologic mapping community are still coping with the costs of the relatively rapid transitions from coverages to shapefiles and from shapefiles to geodatabases.

Text should be stored as .txt, .html, .odt (Open Document Format, ISO/IEC 26300:2006 or its successor), or .pdf files. The patent on LZW compression (commonly used in .tif or .gif images) has expired and patents that may have restricted the use of JPEG compression (.jpg images) have been found invalid, thus the choice between .png, .tif, .jpg, and .gif files for raster images should depend on technical considerations. Vector, or mixed vector-raster, images should be stored as .pdf or .svg files. Tables may be stored as .dbf files, for which there appears to be no published standard but for which documentation is readily available, or as .xml files, which most modern database software can import.

Our desire to endorse open file formats is overshadowed by our need to prescribe a database file format that preserves topology, allows long attribute names, and works well within ArcGIS, thus we specify the use of ESRI's personal geodatabase (.mdb) or file geodatabase (.gdb) file formats for spatial data. To make geologic map data more widely available, we require that data also be released in shapefile formats (see below). We look forward to wider implementation and use of text-based, application-independent delivery formats such as GeoSciML.

Required, As-Needed, and Optional Contents of a Digital Geologic Map Publication

For a map publication named mapXYZ, the publication package should include the files described below. Note that "as needed" elements must be present if they are appropriate to the content of the map publication, for example, if there is a figure 1 in the map publication, then a file Figure1.png (or equivalent) must be present in the digital product. "Optional" elements may or may not be present at the discretion of the author or publisher. Required elements are highlighted in light red; as-needed elements are highlighted in light blue.

mapXYZ.pdf	*Reference map visualization. Publication quality*
mapXYZ-browse.png (.jpg, .tif)	*Browse graphic. A **small** file*
mapXYZ-pamphlet.pdf	*Map pamphlet, as needed*
mapXYZ-metadata.xml	*FGDC metadata. More-or-less human-readable metadata files (.txt, .html) are optional*

mapXYZ-gdb.zip		*When unzipped, this file contains:*	
	mapXYZ.gdb *(file geodatabase folder)* or mapXYZ.mdb *(personal geodatabase file)*		
	mapXYZ.mxd		ArcMap document stored with relative pathnames and including relevant macros
	mapXYZ.pmf		*ArcReader document*
	resources (folder)		
		figures (.png, .pdf, .tif)	*As needed*
		tables (.dbf, .ods, .xls)	*As needed*
		CMU (.pdf, .png, …)	*Optional. Graphic representation of correlation of map-units diagram. Note: eventually this will be superseded by required encoding of CMU within the map geodatabase*
		DMU (.pdf)	*Optional. Additional document for description of map units*
		mapXYZ.style	*ArcGIS style file for area, line and marker symbols used in preferred symbolization of map. Will be largely a subset of the FGDC geology symbol set. Please see the NCGMP09 Web site for a suggested master style file and associated font files. Must include all symbols specified elsewhere in database. Include any non-standard font files referenced by the style file. Unnecessary if appropriate cartographic representations are included in the geodatabase itself*
	mapXYZ-pamphlet.pdf		*Map pamphlet, as needed*
	base.gdb or base.mdb (folder or file)		*As needed; required if base-map geospatial data are not published elsewhere. Otherwise optional*
	mapXYZ-metadata.xml		*FGDC metadata; copy of file referenced above*
mapXYZ-simple.zip		Simple version of database. See below for contents	
mapXYZ-open.zip		*Open version of database. See below for contents*	

The Geodatabase Design

There are required, as-needed, and optional elements in this single-map geologic map geodatabase (fig. 1). Required and as-needed elements are specified below. Optional elements are described in Appendix B. For each element (feature dataset, feature class, non-spatial table) we provide a name, identify the element type, and enumerate the fields (attributes) in the relevant table. Unless otherwise noted, all fields are of data type text (= string). Any length is appropriate, so long as it is sufficient to store the associated values; we recommend 50 characters for ID fields and 255 characters for most other fields. For each field we briefly discuss content and domains where appropriate. For some elements, this is followed by a short example table and further discussion.

The values in certain fields must be defined in the Glossary table or a referenced external data dictionary. Such fields are highlighted in light blue below.

Every feature class and table has a primary key field with a name of the form <TableName_ID>. Where values of this primary key populate a field in another feature class or table, that field has a different name. For example, values of DataSources_ID populate fields named DescriptionSourceID (DescriptionOfMapUnits) and LocationSourceID (point data tables) and DataSourceID (many tables).

If data loaded into a database do not already have user-managed primary keys, we suggest that primary key values be created from a three- or six-letter prefix based on the name of the containing table concatenated with an integer suffix unique to the containing table. The suffix could be the string representation of the ESRI geodatabase-maintained ObjectID included in all geodatabase-registered tables. If all table prefixes are unique within the database, this scheme provides unique identification across the database, as well as some human intelligibility of foreign keys.

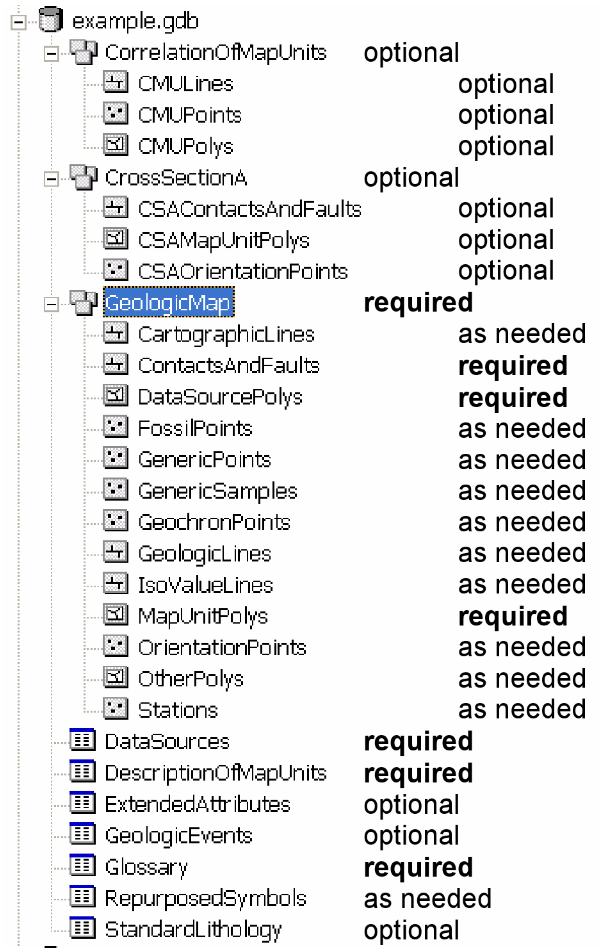

Figure 1. ArcCatalog view of NCGMP09-style geodatabase, showing required, as-needed, and optional database components. As-needed elements must be present if they are appropriate to the content of the map publication. Optional elements may or may not be present at the discretion of the author or publisher. There may be more than one cross-section feature dataset, named CrossSectionA, CrossSectionB, and so on.

General Considerations

This Design Implies a Relational Database

This design relies on relations (relates or relationship classes) between various feature classes and non-spatial tables. These relations include:

- All feature classes and some tables (via fields DataSourceID, LocationSourceID, AnalysisSourceID, DefinitionSourceID) to DataSources (field DataSource_ID) (many-to-one)
- All feature classes and some tables (via fields Type, ExistenceConfidence, IdentityConfidence, ScientificConfidence, …) to Glossary (field Term) (many-to-one)
- Feature class MapUnitPolys (via field MapUnit) to DescriptionOfMapUnits (field MapUnit) (many-to-one).

Figure 2 shows the relationships among the elements of this design. The simple shapefile output version of the database (described below) provides a relate-free version of the data at the cost of truncation of long fields and omission of some database elements.

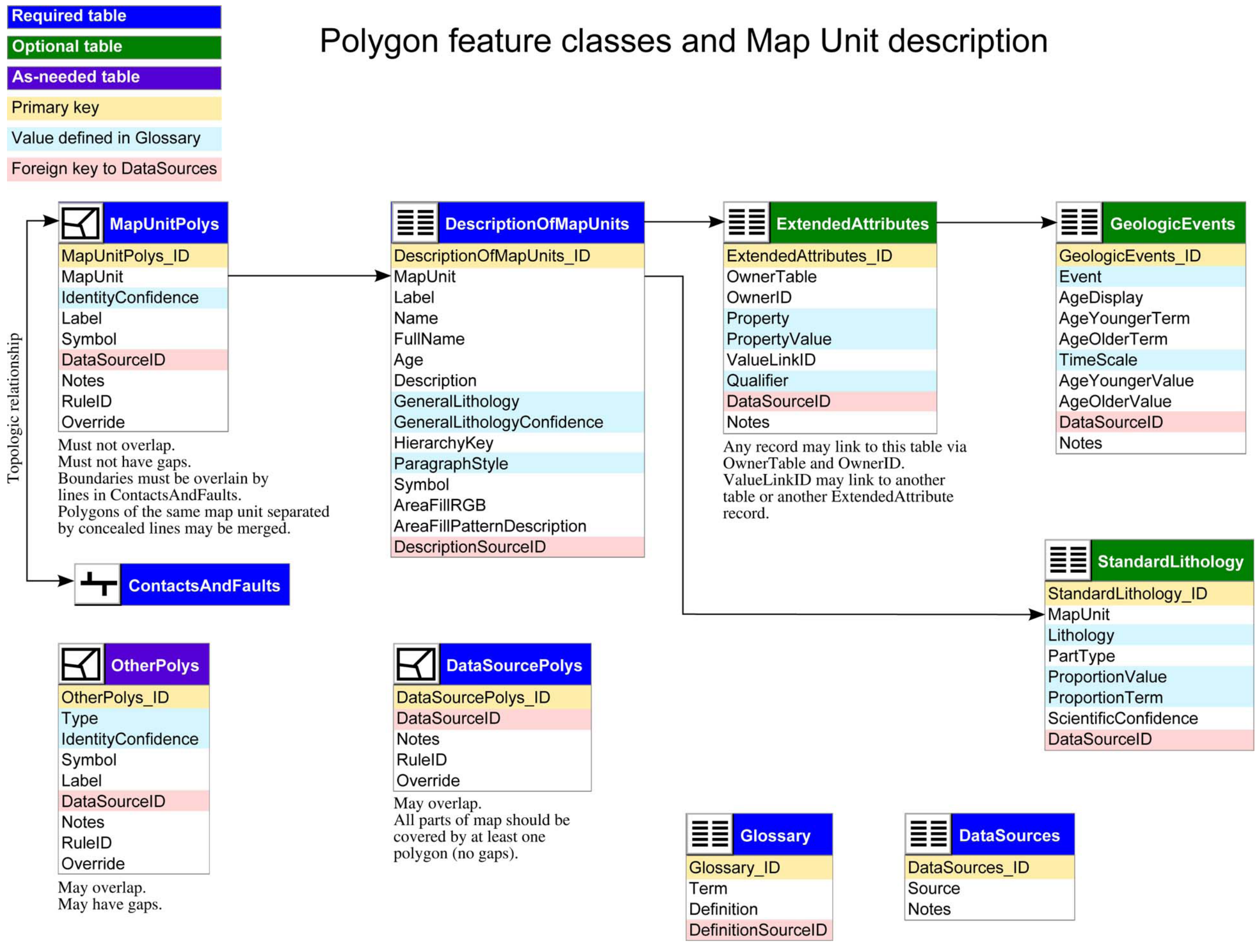

Figure 2A. Entity-relationship diagram of NCGMP09 polygon feature classes and Map Unit description. A higher resolution version is available at *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*.

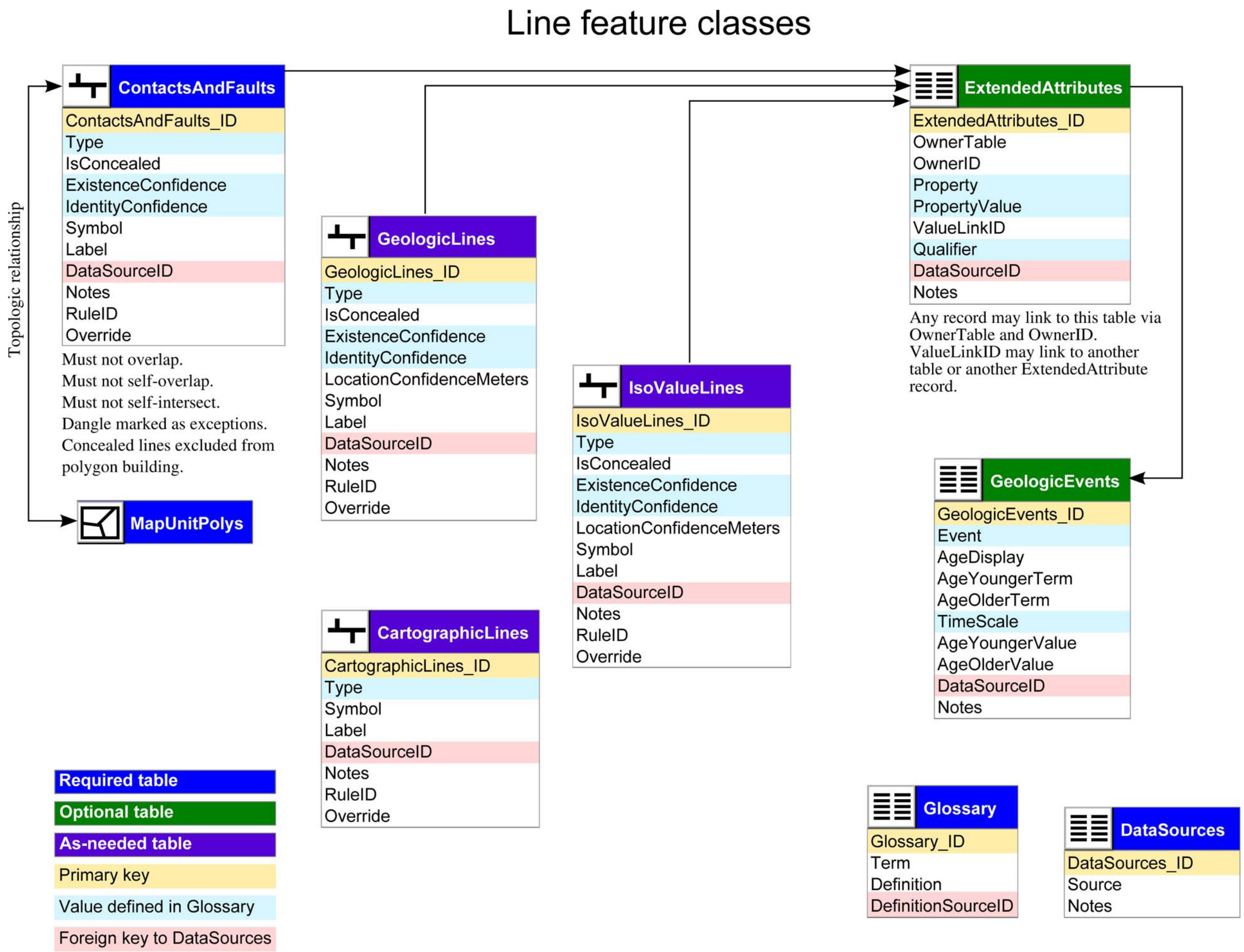

Figure 2B. Entity-relationship diagram of NCGMP09 line feature classes. A higher resolution version is available at *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*.

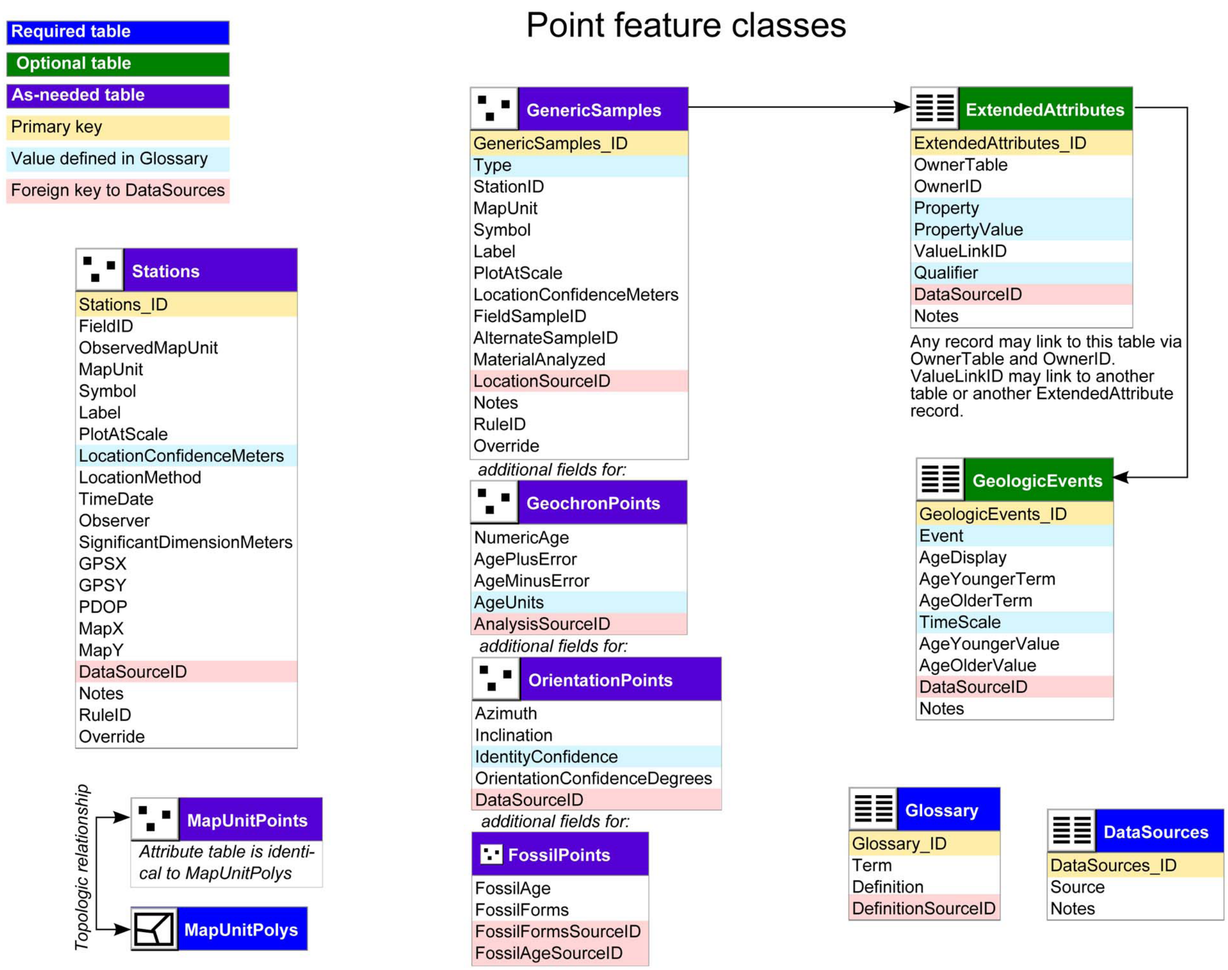

Figure 2C. Entity-relationship diagram of NCGMP09 point feature classes. A higher resolution version is available at *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*.

Type, Label, and Symbol Fields

Most feature classes contain fields *Type*, *Label*, and *Symbol*.

- *Type* is a classifier that specifies what kind of geologic feature is represented by a database element: for instance, a certain line within feature class ContactsAndFaults is a contact, or thrust fault, or water boundary; or a point in GeochronPoints represents a K-Ar date.
- *Label* is the plain-text equivalent of the desired annotation for a feature: for example, "14 Ma," or "^c" which (when used with the FGDC GeoAge font) results in the geologic map-unit label TRc .
- *Symbol* is a reference to a point marker, line symbol, or area-fill symbol that is used on the map graphic to denote the feature: perhaps a star for a K-Ar age locality, or a heavy black line for a fault.

This three-fold division of what at first glance may seem to be one entity is necessary because (1) values of Label commonly are very different from Type values or are formed by convolving Type and IdentityConfidence (for example, "Me" and "questionable" to show "Me?"); (2) special characters, inappropriate for Type values, may be used to enable labeling; and (3) for line features, Symbol is determined by the combination of Type, LocationConfidenceMeters, ExistenceConfidence, and IdentityConfidence.

Polygons, Lines, and Topology: What Goes Where?

By convention, a geologic map depicts the distribution of earth materials on a particular map horizon, commonly the Earth's surface. Map-unit polygons (including water, snowfields, and glaciers) are bounded by contacts, faults, shorelines, snowfield boundaries, scratch boundaries, or the map boundary. With some exceptions, which are unusual enough to require mention, contacts do not separate polygons of the same map unit, though faults may do so. Map-unit polygons may be partially bisected by a fault (that is, using GIS jargon, the fault "dangles").

The distribution of map units on the particular map horizon is recorded in the polygon feature class "MapUnitPolys". Contacts between map units, faults that bound map units, and associated dangling faults are recorded in the line feature class "ContactsAndFaults". Elements of these feature classes participate in topological relations that are described below. Elements are assigned to these feature classes to simplify enforcement of the topological relations (when constructing a geodatabase) and to facilitate topological queries (when using a geodatabase).

Some maps show contacts and faults that are concealed beneath covering units (for example, beneath thin unconsolidated deposits, or beneath open water). These concealed contacts and faults should be recorded in the feature class "ContactsAndFaults", and be coded as IsConcealed = "Y". Such concealed contacts and faults are not involved in topology with MapUnit polygons. Some concealed contacts and faults may dangle.

Many, but not all, geologic maps contain other classes of features that do not participate fully in map topology (for example, fossil localities, fold axes, bedding orientation measurements). Feature classes for encoding such features are described below under "As-needed elements".

We understand that some producers of geodatabases will choose to create polygons and edit linework in the absence of a topology relationship class. For instance, rather than using topology editing tools to synchronously edit shared boundaries between lines and polygons, many users prefer to edit using a procedure involving lines, polygon attribute label points, and the creation of polygons when the linework is finished, without the use of geodatabase topology rules. For the purposes of this design (data delivery), the method used to produce the feature classes does not matter, only that the feature classes in the published database follow the topology rules outlined below.

Directional Lines

Many geologic lines have directionality, equivalent to handedness. Examples are thrust and normal faults, which by convention have ornaments (teeth, tics, bar-and-ball symbols) that point toward the upper (overlying) plate. We prescribe the right-hand rule to store this directionality: such lines should be created or edited (for example, using the 'flip' tool in ArcMap) such that any ornament, or the upper direction in the case of U-D labels on faults, is to the right of the line while traveling from the start of the line to the end of the line.

Required Elements

GeologicMap (feature dataset)

This feature dataset is equivalent to the map graphic: it contains all the geologic content (but not the base map) within the neatline. All elements share a single spatial reference framework. Light blue highlighting indicates fields whose content must be defined in the Glossary table.

MapUnitPolys (polygon feature class)

Fields:

MapUnitPolys_ID	*Primary key. Example Values = MUP1, MUP2, MUP3, and so on. Values must be unique in database as a whole*
MapUnit	*Short plain-text key (identifier) for the map unit. Example values: Qal, Tg, Kit, water, Trc3, and so on. Foreign key to DescriptionOfMapUnits table. Null values not permitted—a mapped polygon must have an assigned map unit*
IdentityConfidence	*How confidently is this polygon identified as MapUnit? Value is usually "certain", "questionable", or "unspecified". Null values not permitted. Suggest setting default value to 'certain'*
Label	*Calculated from MapUnit//Label and IdentityConfidence: if IdentityConfidence = "questionable", then append "?" to MapUnit//Label. Allows for subscripts and special characters. Null values OK*
Symbol	*References an area fill symbol (background color + optional pattern). Area fill symbols must be defined in an accompanying style file. If cartographic representations are used to symbolize map units, the value may be null or blank. Null values permitted*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Notes	*Null values OK. Free text for additional information specific to this polygon*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Topology rules:

- Polygons must not overlap
- Polygons must not have gaps
- Boundaries must be overlain by lines in ContactsAndFaults
- Not all lines in ContactsAndFaults necessarily bound polygons: polygons separated by concealed contacts or faults may have been merged during construction of the database
- Some faults, concealed contacts, and concealed faults may dangle (terminate within polygons) and thus not separate polygons.

Note that open water (lakes, double-line rivers), glaciers, and unmapped areas are polygons, and so have non-null MapUnit values (perhaps water, glacier, unmapped). Water and glacier areas commonly are not labeled (Label=null).

ContactsAndFaults (line feature class)

Fields:

ContactsAndFaults_ID	*Primary key for database record. Example values = COF1, COF2, … Values must be unique in database as a whole*
Type	*Specifies the kind of feature represented by the line. Values could be, for example, 'contact', 'fault', 'waterline', 'glacier boundary', 'map boundary'. Values must be defined in Glossary. Null values not permitted*
IsConcealed	*Values = 'N','Y'. This is a flag for contacts and faults covered by an overlying map unit. Null values not permitted*

LocationConfidenceMeters	*Data type = float. Half-width in meters of positional uncertainty envelope; position is relative to other features in database. Null values not permitted. Recommend value of -9 if value is not available*
ExistenceConfidence	*Values = 'certain', 'questionable', 'unspecified'. Null values not permitted. Suggest setting default value = 'certain'*
IdentityConfidence	*Values: 'certain' , 'questionable, 'unspecified". Null values not permitted. Suggest setting default value = 'certain'*
Symbol	*References a symbol in the accompanying style file. Calculated from Type, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and expected map display scale. Null values OK*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*Can be used to store fault name, or human-readable name for a line feature. To group line segments into a specific structure trace, for example,"San Andreas Fault", use Extended Attributes. Typically null*
Notes	*Free text for additional information specific to this feature. Null values OK*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Topology rules:

- Must not overlap.
- Must not self-overlap.
- Must not self-intersect.
- Must not have dangles, unless marked as exceptions. Most dangling-line exceptions should be Type='fault' or be Type='contact' and IsConcealed = 'Y'.

Map boundaries, open water boundaries, and snowfield and glacier boundaries all bound map-unit polygons and in this sense are contacts. They are thus included in this feature class. Unit-bounding fault lines are legitimate elements of this feature class and should not be coincident with contacts.

Lines shown as "contact", "contact inferred" and "contact approximately located" are Type = "contact", but have differing LocationConfidenceMeters, ExistenceConfidence, and (or) IdentityConfidence. While these lines are all Type = 'contact', they are typically symbolized differently and the symbolization may change with map scale.

We recommend using "blank" as the value of Symbol for scratch boundaries (where no line is drawn between adjoining polygons, also known as wash boundaries); scratch boundaries are occasionally used for contacts with exceptionally large values of LocationConfidenceMeters. Suggested values for Type include:

contact
contact, internal
contact, gradational
contact, unconformable
fault
fault, normal
fault, reverse
fault, thrust
scratch boundary
glacier boundary
waterline
map boundary (or, map neatline)

This list is derived from the FGDC standard, sections 1, 2, 30, and 31. Other values are possible (for example, see FaultType and ContactType vocabularies at *https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG*). In all cases, note that modifiers such as "approximate", "certain", "concealed", and "queried" are not encoded in Type. These modifiers reflect the convolution of LocationConfidenceMeters, ExistenceConfidence, IdentifyConfidence, and visualization scale.

DataSourcePolys (polygon feature class)

Fields:

DataSourcePolys_ID	*Primary key. Values = DSP1, DSP2, DSP3, … Values must be unique to the database*
DataSourceID	*Foreign key DataSources table, indicating source for map data within polygon. Null values not permitted*
Notes	*Free text for additional information specific to this feature. Null values OK*

Topology rules:

- Polygons may overlap
- Polygon boundaries may in part be coincident
- All parts of map area should be encompassed by at least one polygon (no gaps).

This feature class contains polygons that delineate data sources for all parts of the map. These sources may be a previously published map, new mapping, or mapping with a certain technique (for example, "compiled by A.N. Author from 1:40,000-scale air photos"). For a map with one data source, for example all new mapping, this feature class contains one polygon that encompasses the map area.

DescriptionOfMapUnits (non-spatial table)

This table captures the content of the Description of Map Units (or equivalent List of Map Units and associated pamphlet text) included in a geologic map.

Fields:

DescriptionOfMapUnits_ID	*Primary key: DMU1, DMU2, DMU3; ExtendedAttributes table OwnerID is a foreign key using this value. Null values not permitted*
MapUnit	*Short ASCII string that identifies map unit: Qal, Tec, Qvt. Unit abbreviations must be unique in the database. Values in this field are the link (foreign key) between this table and the MapUnitPolygon table. Null values OK, and are commonly associated with headings or headnotes. Use of special characters is not recommended in this field*
Label	*Text string used to place label in map display; includes graphic elements such as special fonts and formatting for subscripts. For example, Triassic Newark Formation might be "<font=FGDCGeoAge>#n". Null values OK for units that do not appear on map or are not labeled, for example, headings, headnotes, water, glacier, some overlay units*
Name	*Boldface name in traditional DMU, identifies the unit within its hierarchical context. Examples: 'Chinle Formation', 'Shnabkaib Member'. These names should be verified in the U.S. Geologic Names Lexicon (GEOLEX); if your usage does not agree with GEOLEX's, notification should be submitted to the Lexicon website. Null values OK*
FullName	*Full name of unit, including identification of containing higher rank units, for example, 'Shnabkaib Member of Moenkopi Formation'. This is the text you would like to see as fly-out when cursor lingers over polygon in an electronic map display. See Lexicon-related note in "Name", above. Null values OK (for example, for headings, headnotes, geologic units not shown on map)*
Age	*Stratigraphic range (or, for intrusive and extrusive rocks, age), listed highest (youngest) first. Free-format text, as shown within parentheses in traditional DMU. Null values may be used for map units that inherit Age from a parent unit, or for headings, headnotes, or overlay units. To designate with more resolution than permitted by DMU standards, or to record multiple stratigraphic ranges or ages (for example, deposition and metamorphism) for a unit, create entries in ExtendedAttributes and GeologicEvent tables*
Description	*Free-format text description of map unit. Commonly structured according to one or more accepted traditions (for example, lithology, thickness, color, weathering and outcrop characteristics, distinguishing features, genesis, age constraints) and terse. Allows markup (for example, HTML) specification of new paragraphs, superscripts and subscripts, and geologic-age font (sans-serif and with special characters). Null values OK*
HierarchyKey	*Has form nn-nn-nn, nnn-nnn, or similar. Numeric, left-padded with zeros, dash-delimited. Each HierarchyKey fragment of each row MUST be the same length to allow text-based sorting of the DMU entries. These strings are useful for resolving queries involving hierarchical relationships, for example, 'find all members of formation x', 'what is the parent unit of map unit y'. Null values not permitted. Table 1, below, illustrates the use of HierarchyKey to describe the structure of a complex Description of Map Units*

ParagraphStyle	*Values are Heading1st, Heading2nd, Heading3rd, …, Headnote, DMU1, DMU2, DMU3, or similar. Formatting associated with a paragraph style should be explained with a definition of the style in the glossary. Null values not permitted*
AreaFillRGB	*{Red, Green, Blue} tuples that specify the suggested color (for example, '255,255,255', '124,005,255') of area fill for symbolizing this MapUnit. Use of consistent syntax is important to enable computer programs to read this field and display intended color. Each color value is an integer between 0 and 255; values are zero-padded so that there are 3 digits to each R, G, and B value; and color values are separated by commas with no space: NNN,NNN,NNN. Especially important to non-ESRI users unable to use the .style file. Null values OK (for example, headings, headnotes)*
AreaFillPatternDescription	*Text description (for example, 'random small red dashes') provided as a convenience for users who must recreate symbolization. Especially important to non-ESRI users unable to use the .style file. Null values OK (for example, headings, headnotes, unpatterned map units)*
Symbol	*References an area fill symbol in the accompanying style file that is used for symbolizing the unit on the map.*
DescriptionSourceID	*Foreign key to DataSources. Identifies source of DescriptionOfMapUnits entry. Null values not permitted*
GeneralLithology	*Term to categorize the map unit based on lithologic and genetic character, from NGMDB standard term list (*Appendix A*); see also discussion in "Extensions to traditional geologic map content", above. Null values OK for headings and unmapped units*
GeneralLithologyConfidence	*Describes appropriateness of GeneralLithology term for describing the map unit (Appendix A). Null values OK for headings and unmapped units*

The traditional Description of Map Units (DMU), or equivalent List of Map Units with descriptions in an accompanying pamphlet, is strongly formatted and typically hierarchical. The hierarchy can carry a significant amount of information. This table encodes the traditional DMU as specified in Suggestions to Authors (Hansen, W.R., ed., 1991, Suggestions to Authors of the Reports of the United States Geological Survey, 7th edition: Washington, D.C., U.S. Government Printing Office, p. 49-52) without loss of information and—with one exception—without imposing additional structure or content. We have added GeneralLithology and GeneralLithologyConfidence fields to the DMU table in order to provide a foundation for simple, regional, lithologic queries. Additional lithologic information may be included in the optional StandardLithology table or a user-defined table (see Encoding additional information).

The text description in the DMU is an essential part of this database, just as it has always been an essential part of the printed map. The parsing of DMU descriptions into data fields could someday prove useful (for example, to facilitate standard queries), but would be much easier if descriptions become more uniform and predictable in format. However, specifications for the format of these descriptions are highly general in nature (for example, Hansen, 1991, p. 187). This certainly has its advantages. Are there also advantages to a more structured and predictable format? We do not address this issue here but are interested in discussing it. If you have comments or guidance, please contact us at *ncgmp09@flagmail.wr.usgs.gov*.

All map units and overlay units assigned to polygons on the map (or in any of the cross sections), and all headings and headnotes beneath "DESCRIPTION OF MAP UNITS" (or LIST OF MAP UNITS) have an entry in this table. The entries should include map units that are traditionally not listed in the DMU/LMU such as 'water', 'glacier', and 'unmapped area', and all geologic units that are listed in the DMU/LMU as parent units but are not represented as polygons on the map.

The text of headings and headnotes should be stored in the Description field. Heading and headnote text should have initial capitalization only and no font specifications—these are given by ParagraphStyle.

The ParagraphStyle field eases automatic construction of a traditional text DMU or LMU from DescriptionOfMapUnits. ParagraphStyle values can, with difficulty, be calculated from HierarchyKey, text in the Description field, and feature class MapUnitPolys. The partial redundancy between HierarchyKey and ParagraphStyle (Table 1) allows some automated checking of DescriptionOfMapUnits for logical consistency.

DescriptionSourceID commonly points to Source = 'This report' or Source = 'Modified from <earlier report>'.

Table 1. Truncated, abbreviated Description of Map Units (3rd column, headings and unit names only) from a recent geologic map of northwest Washington, with paragraph styles and HierarchyKey.

HierarchyKey	Paragraph Style		Headings and Map Units
1	Heading2		***Unconsolidated deposits***
1-1	Heading3		**Nonglacial deposits**
1-1-1	DMU1	Qa	**Alluvium of valley bottoms (Holocene and Pleistocene)**
1-1-2	DMU1	Qu	**Alluvium (Holocene and Pleistocene)**
1-1-3	DMU1	Qt	**Talus deposits (Holocene and Pleistocene)**
1-1-4	DMU1	QTl	**Landslide deposits (Holocene, Pleistocene, and Pliocene?)**
1-1-5	DMU1	Qlh	**Lahars (Holocene and Pleistocene)**
1-2	Heading3		**Glacial deposits**
1-2-1	DMU1	Qag	**Alpine glacial deposits (Holocene and Pleistocene)**
1-2-2	DMU1	Qga	**Deposits of alpine glaciers and Cordilleran Ice Sheet (Holocene and Pleistocene)**
1-2-3	DMU1		**Deposits of Vashon stade of Fraser glaciation of Armstrong and others (1965) (Pleistocene)**
1-2-3-1	DMU2	Qvr	**Recessional outwash deposits**
1-2-3-2	DMU2	Qvt	**Till**
1-2-3-3	DMU2	Qva	**Advance outwash deposits**
1-2-4	DMU1	Qud	**Upland deposits (Holocene and Pleistocene)**
			-----many headings and map units omitted-----
5	Heading2		***Orogenic and pre-orogenic rocks mostly west of Straight Creek Fault***
5-1	Heading3		**Rocks northeast of Darrington-Devils Mountain Fault Zone**
5-1-1	Heading4		Northwest Cascade System
5-1-1-1	Heading5		***Rocks of Autochthon***
5-1-1-1-1	DMU1	KJn	**Nooksack Formation (Early Cretaceous to Middle Jurassic)**
5-1-1-1-1-1	DMU2	Jnw	**Wells Creek Volcanic Member**
5-1-1-2	Heading5		***Welker Peak and Excelsior nappes***
5-1-1-2-1	DMU1	KJb	**Bell Pass mélange (Cretaceous to Late Jurassic)**
5-1-1-2-1-1	DMU2	KJya	**Yellow Aster Complex of Misch (1966) (Paleozoic or older protolith age)**
5-1-1-2-1-2	DMU2	KJts	**Twin Sisters Dunite of Ragan (1961, 1963)**
5-1-1-2-1-3	DMU2	KJv	**Vedder Complex of Armstrong and others (1983) (pre-Permian protolith age)**
5-1-1-2-2	Heading6		**Chilliwack River terrane**
5-1-1-2-2-1	DMU1	JTrc	**Cultus Formation of Brown and others (1987) (Early Jurassic and Late Triassic)**
5-1-1-2-2-2	DMU1	PDc	**Chilliwack Group of Cairnes (1944) (Permian, Carboniferous, and Devonian)**
5-1-1-3	Heading5		***Shuksan nappe***
5-1-1-3-1	Heading6		**Easton terrane**
5-1-1-3-1-1	DMU1	Ket	**Tonalite gneiss of Hicks Butte (Early Cretaceous)**
5-1-1-3-1-2	DMU1		**Easton Metamorphic Suite**
5-1-1-3-1-2-1	DMU2	Ked	**Darrington Phyllite (Early Cretaceous)**
5-1-1-3-1-2-2	DMU2	Kes	**Shuksan Greenschist (Early Cretaceous)**

DataSources (non-spatial table)

Fields:

DataSources_ID	*Primary key. Example values = DAS1, DAS2, DAS3, … Null values not permitted*
Source	*Plain-text short description that identifies the data source. By convention, for DataSources_ID = DAS1, Source = 'This report'. Null values not permitted*
Notes	*Notes on source, providing more complete description of processing or data acquisition procedure. Can include a full citation and (or) URL. Null values OK*

Some example DataSources records:

DataSources_ID	Source	Notes
DAS1	This report	Field compilation automated by A. Digitdroid, using georeferenced scan of green-line mylar, ESRI ArcScan tools, and manual editing
DAS2	This report, interpreted from 6ft lidar DEM	Data acquired winter 2003-2004 by Puget Sound Lidar Consortium
DAS3	This report, Ralph Haugerud field data, 2005	
DAS4	USGS Open-file Report 2004-197	
DAS5	C. A. Hopson, written communication 2005	Sketch map of lower Chelan creek, used for tonalite phase - gabbro phase contact. University of California-Santa Barbara, written communication 17 July 2005, scale 1:24,000
DAS6	Beta Laboratories, Report 1999-451.	K-Ar dates determined using constants from Dalrymple, 1985.
DAS7	Jackson, J.A., 1997	Cited in Glossary table for sources of term definitions. Jackson, J.A., 1997, Glossary of Geology: Alexandria, VA, American Geologic Institute, 657 p.
DAS8	Modified from DAS4	S. Richard digitized 3 new large landslides based on 2006 air photography.

All features and table entries need to be associated with a data source. For maps that contain all new information and use a single vocabulary source, this table will be very short. For compilations with data from many sources that have been edited and (or) reinterpreted so that the data source has effectively been changed, this table becomes longer and more useful. See ChangeLog (below) for advice on maintaining accurate DataSourceID values.

Glossary (non-spatial table)

Fields:

Glossary_ID	*Primary Key. Example values = GLO1, GLO2, GLO3, … Null values not permitted*
Term	*Plain-language word for a concept. Values must be unique within database as a whole. Example values: granite, foliation, syncline axis, contact, thrust fault, certain, low, fission track, K-Ar. Null values not permitted*
Definition	*Plain-language definition of Term. Null values not permitted*
DefinitionSourceID	*Foreign key to DataSources. Identifies source of Definition. Null values not permitted*

Some example Glossary records:

Glossary_ID	Term	Definition	DefinitionSourceID
GL001	contact	Line denoting unfaulted boundary (depositional, intrusive, metamorphic...) between two geologic map units	DAS1
GL002	Biotite isograd	Line marking first appearance, going up-grade, of newly formed biotite in metamorphosed siltstones and shales	DAS1

Terms that require definition include all values of Type, ExistenceConfidence, IdentityConfidence, ScientificConfidence, GeneralLithology, GeneralLithologyConfidence, Qualifier, Property, ParagraphStyle, AgeUnits, and TimeScale. Lithology terms used in GeneralLithology must not be redefined from the NGMDB standard. If there are no intellectual property restrictions, it is permissible and recommended to replicate all or part of an external glossary here. Provide appropriate credit for definitions via the DefinitionSourceID. If such restrictions preclude including a definition in the glossary, the term should still be present, with a note in the definition field to see the publication cited by the definition-source record. 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.

As-Needed Elements

Some geologic maps contain types of features that do not directly participate in map topology. If such features are present in a geologic map report, they should be digitally encoded in the map geodatabase. If such elements are not present, the corresponding feature classes need not be part of the geodatabase, thus these feature classes are *as-needed* elements. Such features include foliation, lineation, and bedding measurements; sample localities; various sample-based fossil, geochemical, and geochronological analyses; localities of field photographs; fold axes (more precisely, traces of fold hinge surfaces); structure contours; concentration contours; cross-section lines; former ice limits and ice flow lines; and areas of mineralization or man-made fill (both commonly depicted as overprints).

There are many such feature types and there are many ways to partition these types into feature classes. At one extreme, each feature type can be represented by a separate feature class—in which case, the Type attribute of the feature class becomes redundant. At the other extreme, all feature types with the same geometry (point, line, polygon) can be assigned to a single feature class and differentiated by the Type attribute. In this case, there is a temptation to add a plethora of attributes to the feature class, many of which are likely to be unpopulated for many features. In discussions with colleagues we have been unable to agree on a "best" partitioning: different database use cases suggest different partitioning. For this reason we do not prescribe such as-needed feature classes. Instead we present guidelines for designing and naming feature classes, discuss principles that govern the structure of point data, and describe several examples of as-needed feature classes. All of these feature classes reside within the GeologicMap feature dataset.

Guidelines for Naming and Designing Additional Polygon, Line, and Point Feature Classes

- The feature class name should emphasize the identity of the class.
- The feature class name will include "Points", "Lines", or "Polys" except where this is redundant (Stations, not StationPoints).
- Feature class names and attribute names will commonly be compound words. Compound words will be written in CamelCase, without spaces or underscores (with one exception, given below).
- Every feature class will have a primary key field named *FeatureClassName*_ID. This is the sole exception to the "no underscores" guideline.
- Every feature class will have at least one sourceID field. If each feature has a single source, this field will typically be named "DataSourceID". If the data source is compound (for example, sample analyses, for which the sample location commonly has a different source than the associated sample analysis), there should be multiple sourceID fields, (for example, LocationSourceID and AnalysisSourceID).
- ExistenceConfidence, IdentityConfidence, LocationConfidenceMeters, and similar confidence fields will be included as appropriate.
- Measured attributes, or attributes that represent real-world quantities (strike, dip, concentration, location confidence) will be data type = float. It may be necessary to define, and document in the feature-class metadata, conventions for representing nil values, for example, -9 = "Not available".
- All attributes of a feature class should be populated for most features. If a feature class has one or more attributes that are not applicable to some subset of features in the class, consider splitting the class into multiple classes, each with a more-appropriate subset of attributes. If some attributes have many null values because the information is not available, consider representing this attribute using the ExtendedAttributes table.
- Consider combining small feature classes that have common attribute structures.

The remainder of this section describes as-needed feature classes OrientationPoints, GeochronPoints, Stations, GeologicLines, CartographicLines, IsoValueLines, and OtherPolys. Other possible as-needed feature classes include GeochemPoints, PhotoPoints, FieldNotePoints, SamplePoints, FossilPoints, FoldLines, and DikeLines. We specifically request your comments on this set of feature classes and names, in order to help converge on standard naming conventions; please send comments to *ncgmp09@flagmail.wr.usgs.gov*.

Structure of Point Data

Observations of structure orientations, mineral occurrences, fossil occurrences, and collections of samples for geochemical, paleontologic, geochronologic, and other kinds of analyses are made at field stations. There are two modes for representing such observations, samples, and related analyses and their accompanying locations:

1. A normalized mode, in which a "Stations" feature class stores location information and data specific to the station, a non-spatial Sample table stores information on samples related to stations, and other non-spatial tables store observations and analyses, one for each observation or analysis type, related to either a sample or station.
2. A denormalized mode, in which there is a separate feature class for each type of observation or analysis that requires a special attribute structure and that in some cases duplicates station location and sample information.

Each mode has advantages. The first allows error-resistant editing of location and sample information (the station data is recorded in only one place) and is well suited for a data management and archiving system. The second facilitates symbolization and organization of data in map layers in a GIS viewing environment (no joins or filtering required), and is more convenient for exporting analytical information from a source geodatabase by simply copying the relevant feature class.

Because NCGMP09 is designed for publishing geologic map data, not creating such data, we endorse the second mode. We note that to create a compliant database it is likely to be useful to start in the first mode, creating a Stations point feature class with related data tables, including a Samples table, and from these create the appropriate data-type-specific point feature classes that will be included in the delivery database. Below, we recommend attributes that should be included for any point data feature class, and three example point feature classes, one for measurements made directly at a station (OrientationPoints), one for measurements related to a sample collected at a station (GeochronPoints), and one for stations (Stations). None of the example feature classes is required, though all are likely to be needed for many maps.

Point Feature Classes: General

Each point feature class shall contain the following fields:

TableName_ID	*Primary Key. Substitute actual table name for 'TableName'. Null values not permitted*
Type	*Values must be defined in Glossary or by reference to external glossary. Null values not permitted*
StationID	*Foreign key to* Stations *point feature class. If the table represents stations, this field is not required—it would duplicate the Stations_ID primary key field. Null values OK for data that are not associated with other data from the same station location*
MapUnit	*One commonly would like to know what map unit an analysis or observation pertains to. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits. *Null values not permitted*
Symbol	*References a symbol in the accompanying style file. Null values OK*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*Text to accompany the symbol. For structure data this is typically the dip or plunge of the measured orientation. Null values OK*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope for location of the observation or sample locale. Null values not permitted. Recommend value of -9 if value is not available*
PlotAtScale	*Data type = float. At what scale (or larger) should this observation or analysis be plotted? At smaller scales, it should not be plotted. Useful to prevent crowding of display at small scales and to display progressively more data at larger and larger scales. Value is scale denominator. Null values not permitted, default value is 0 (display at all scales)*
Notes	*Null values OK. Free text for additional information specific to this feature*
LocationSourceID	*Foreign key to DataSources. Identifies source of point location. Null values not permitted*
DataSourceID	*Foreign key to DataSources. Identifies source of data at this point. Null values not permitted*

Sample-oriented point feature classes shall also have the fields:

FieldSampleID	*Sample ID given at time of collection. Null values OK*
AlternateSampleID	*Museum #, lab #, and so on. Null values OK*
MaterialAnalyzed	*Null values OK*

Some Examples of As-Needed Feature Classes

OrientationPoints (point feature class)

Point structure data (bedding attitudes, foliation attitudes, slip vectors measured at a point, and so on) may be recorded in OrientationPoints, one point per measurement. This table has fields:

OrientationPoints_ID	*Primary Key. Example values = ORP1, ORP2, ORP3, … Null values not permitted*
Type	*Values must be defined in* Glossary *or by reference to external glossary. Null values not permitted*
StationID	*Foreign key to* Stations *point feature class. Null values OK*
MapUnit	*Map unit in which the orientation was measured. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits*. Null values not permitted*
Symbol	*References a symbol in the accompanying style file. Null values OK*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*Text to accompany displayed symbol, typically the dip or plunge value for the measured orientation. Null values OK*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope for the observation locale. Null values not permitted. Recommend value=-9 if value is not available*
PlotAtScale	*Data type = float. At what scale (or larger) should this observation or analysis be plotted? At smaller scales, it should not be plotted. Useful to prevent crowding of display at small scales and to display progressively more data at larger and larger scales. Value is scale denominator. Null values not permitted, default value is 0 (display at all scales)*
Notes	*Null values OK. Free text for additional information specific to this feature*
LocationSourceID	*Foreign key to DataSources. Identifies source of point location. Null values not permitted*
DataSourceID	*Foreign key to DataSources. Identifies source of data at this point. Null values not permitted*
Azimuth	*Data type=float. Values limited to range 0-360. Strike or trend, measured in degrees clockwise from geographic North. Use right-hand rule (dip is to right of azimuth direction). Horizontal planar features may have any azimuth. Null values not permitted*
Inclination	*Data type=float. Values limited to range -90 to 90. Dip or plunge, measured in degrees down from horizontal. Negative values allowed when specifying vectors (not axes) that point above the horizon, for example, paleocurrents. Types defined as horizontal (for example, horizontal bedding) shall have Inclination=0. Null values not permitted*
IdentityConfidence	*Values = 'certain', 'questionable', 'unspecified'. Specifies confidence that observed structure is of the type specified. Null values not permitted*
OrientationConfidenceDegrees	*Data type=float. Estimated circular error, in degrees. For planar features, error in orientation of pole to plane. Null values not permitted*

The Type field identifies the kind of feature for which the orientation was measured, for example, bedding, overturned bedding, stretching lineation, open joint. Type definitions (in the Glossary table) shall specify the orientation-measurement convention for that Type (strike and dip, trend and plunge, dip direction and dip, and so on). Data creators should ensure that multiple measurements at a single station (for example, bedding and cleavage) have the same StationID. Records in the optional ExtendedAttributes table (see Appendix B) may be used to represent relationships between measurements (for example, lineation in foliation, intersection lineation to intersecting foliations).

GeochronPoints (point feature class)

GeochronPoints_ID	*Primary key. Values = GCR1, GCR2, GCR3, … Null values not permitted*
StationID	*Foreign key to Stations point feature class. Null values OK*
Type	*The geochronological method (K-Ar, radiocarbon, mineral - whole-rock Rb-Sr isochron, and so on) used to estimate the age. Values must be defined in* Glossary *or by reference to external glossary. Null values not permitted*
MapUnit	*Map unit from which the analyzed sample was collected. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits*. Null values not permitted*

Symbol	*References a symbol in the accompanying style file. Null values OK*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*What text should accompany the symbolization? Null values OK*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope. How well located is the observation or sample locale? Null values not permitted. Recommend value of -9 if value is not available*
PlotAtScale	*Data type = float. At what scale (or larger) should this observation or analysis be plotted? At smaller scales, it should not be plotted. Useful to prevent crowding of display at small scales and to display progressively more data at larger and larger scales. Value is scale denominator. Null values not permitted, default value is 0 (display at all scales)*
Notes	*Null values OK. Free text for additional information specific to this feature*
DataSourceID	*Foreign key to DataSources. Identifies source of data at this point. Null values not permitted*
NumericAge	*Data type = float. Appropriate value is the interpreted (preferred) age calculated from geochronological analysis, not necessarily the date calculated from a single set of measurements. Null values not permitted*
AgePlusError	*Data type = float. Record type of error (RMSE, 1 sigma, 2 sigma, 95% confidence limit) in Notes field. Null values OK*
AgeMinusError	*Data type = float. Record type of error (RMSE, 1 sigma, 2 sigma, 95% confidence limit) in Notes field. Null values OK*
AgeUnits	*Units for numeric values in NumericAge, AgePlusError, and AgeMinusError. Values = years, Ma, ka, radiocarbon ka, calibrated ka, and so on. These values shall be defined in* Glossary. *Null values not permitted*
FieldSampleID	*Null values OK*
AlternateSampleID	*Null values OK*
MaterialAnalyzed	*Null values OK*

Use the Type field to identify the geochronological method (K-Ar, radiocarbon, mineral – whole rock Rb-Sr isochron, and so on). Analytical data may be represented using the optional ExtendedAttributes table, or in an analysis-specific table such as KArPoints if there are many data with a single analysis type.

Stations (point feature class)

If a map author chooses to include station information in digital publication, we suggest the following fields. A Stations feature class may be extremely useful during initial creation of a map database.

Fields:

Stations_ID	*Primary Key. Example values = STA1, STA2, STA3 ... Unique in database. Null values not permitted*
FieldID	*Identifier assigned by person who originally located station, for example, DRS09-234. Commonly a key to a field sheet and (or) field notebook*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope. How well located is the station? Null values not permitted. Recommend value of -9 if value is not available*
ObservedMapUnit	*The map unit identified in the field (or interpreted from remote sensing) as outcropping at the station. Foreign key to* DescriptionOfMapUnits. *Null values OK*
MapUnit	*Unit on map in which the station is located. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits. *Null values not permitted*
Notes	*FreeText; any observation narrative associated with station*
Symbol	*Identifier for symbol to use in map portrayals of station location. Null values indicates station should not be shown in map display*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*Text string to display on map portrayal next to station symbol. Null values OK*

PlotAtScale	*Data type = float. At what scale (or larger) should this observation or analysis be plotted? At smaller scales, it should not be plotted. Useful to prevent crowding of display at small scales and to display progressively more data at larger and larger scales. Value is scale denominator. Null values not permitted*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*

A stations point feature class might also include these fields:

TimeDate	*Time and date of observation at station*
Observer	*Name of the person who located station*
SignificantDimensionMeters	*Significant dimension of exposure (for example, thickness of stratigraphic section, depth of auger hole, or least diameter of outcrop), in meters. Null values OK*
LocationMethod	*Term that categorizes technique used to determine station location. Example values = 'Recreational GPS', 'Survey grade GPS', 'By inspection', 'By offset', … Terms must be defined in Glossary table.*
GPSX	Measured GPS coordinate (easting). *May differ from map coordinate because of GPS error or (more likely) base map error*
GPSY	Measured GPS coordinate (northing). *May differ from map coordinate because of GPS error or (more likely) base map error*
PDOP	*Data type=float. Predicted Dilution Of Precision; an estimator of GPS accuracy*
MapX	*Station coordinate (easting) as compiled on the base map; base map should be identified in the* DataSources *record*
MapY	*Station coordinate (northing) as compiled on the base map; base map should be identified in the* DataSources *record*

GeologicLines (line feature class)

Dikes, coal seams, ash beds, other kinds of key beds, anticline and syncline hinge-surface traces, and isograds are commonly shown on geologic maps as lines that share three properties:

(a) They do not participate in map-unit topology
(b) They correspond to features that exist within the Earth and may be concealed beneath younger, covering material; and
(c) They are likely to be located with an accuracy that can be estimated.

Feature class GeologicLines suffices to store such features. It has fields:

GeologicLines_ID	*Primary key. Values = GEL1, GEL2, GEL3, … Values must be unique in database as a whole. Null values not permitted*
Type	*Values= 'syncline hinge surface trace', 'biotite isograd', … Values must be defined in glossary or by reference to external glossary. Null values not permitted*
IsConcealed	*Values = 'N','Y'. Flag for lines covered by overlying map unit. Null values not permitted*
LocationConfidenceMeters	*Data type = float. Half width in meters of positional uncertainty envelope. Null values not permitted. Recommend value of -9 if value is not available*
ExistenceConfidence	*Values = 'certain', 'questionable', 'unspecified'. Null values not permitted. Suggest setting default value = 'certain'*
IdentityConfidence	*Values: 'certain', 'questionable', 'unspecified'. Null values not permitted. Suggest setting default value = 'certain'*
Symbol	*References a symbol in the accompanying style file. Calculated from Type, IsConcealed, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and expected visualization scale*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*Typically blank, can be used to store fold name, or other human-readable name for each line feature. To group line segments (for example, concealed and not-concealed segments) into a specific structure trace, the optional* ExtendedAttributes *table can be used. Null values OK*
Notes	*Null values OK. Free text for additional information specific to this feature*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*

Topology rules:

- Must not self-overlap.
- Must not self-intersect.

'Anticline', 'approximately located anticline', 'concealed anticline', and 'inferred anticline' are all Type = 'anticline' but have differing values of IsConcealed, LocationConfidenceMeters, ExistenceConfidence, and (or) IdentityConfidence.

Note that these features could be divided thematically into several feature classes, for example, into FoldLines, KeyBedLines, DikeLines, and IsogradLines.

CartographicLines (line feature class)

Some lines on maps (for example, cross-section lines) have no real-world physical existence, such that LocationConfidenceMeters, ExistenceConfidence, and IdentityConfidence attributes are meaningless, and are never shown as concealed beneath a covering unit, and do not participate in map-unit topology. These lines can be stored in a CartographicLines feature class with fields:

CartographicLines_ID	*Primary key. Values = CAL1, CAL2, CAL3, … Values must be unique in database as a whole. Null values not permitted*
Type	*Term that categorizes what the line represents. Values must be defined in* Glossary *table. Null values not permitted*
Symbol	*References a symbol in the accompanying style file. May be calculated from Type*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*Typically blank, can be used to store cross-section name, or other human-readable name for a line feature. Null values OK*
Notes	*Free text for additional information specific to this feature. Null values OK*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

IsoValueLines (line feature class)

Structure contours, concentration isopleths, and hydraulic head contours share the properties of (a) having an associated value (elevation, concentration, hydraulic potential) that is a real number, (b) having a definable uncertainty in their location, and (c) describing an idealized surface that need not be shown as concealed beneath covering map units. Such lines could be stored in feature class IsoValueLines with fields:

IsoValueLines_ID	*Primary key. Values = IVL1, IVL2, IVL3, … Values must be unique in database as a whole. Null values not permitted*
Type	*Term that specifies the represented feature. Example values= 'top of Big Muddy seam', 'ppm Sr', 'hydraulic potential in Stoneyard aquifer'. Values must be defined in* Glossary *table. Definition must give units for associated Value field. Null values not permitted*
Value	*Date type=float*
Symbol	*References a symbol in the accompanying style file. Calculated from Type*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Label	*Typically blank, can be used to store human-readable name for a line feature. Null values OK*
Notes	*Free text for additional information specific to this feature. Null values OK*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*

OtherPolys (polygon feature class)

Often we show underlying material, or overlying material, or some additional aspect of earth materials (dike swarm, alteration zone, and so on) with an overlay. On a map graphic, such an overlay is commonly shown by a pattern—diagonal lines, scattered red dots, or other—overprinted on the map-unit color and (optional) map-unit pattern. The topological relations of these overlays are likely to be complicated (for example, alteration area boundary does not coincide with bedrock map-unit boundaries, but does coincide with unconsolidated-deposit boundaries) and not easily prescribed by a simple set of rules. On many published maps the edges of most overlay polygons are shown without a bounding line (that is, a scratch boundary). Such features may be represented in the feature class “OtherPolys”. If there are many Types of overlay polygons, and especially if some Types have additional attributes, these overlay polygons may be divided into multiple feature classes, with the division based on attributes and theme.

If an overlay polygon represents a unit listed in table DescriptionOfMapUnits, use MapUnit or Name as the Type value in OtherPolys and summarize the description of the unit in the Definition field of the Glossary table. In the Notes field of the Glossary entry direct the reader to the DMU entry. Note that a validation script may then identify certain “errors” in the database, such as a row in DescriptionOfMapUnits without a corresponding polygon in MapUnitPolys. These “errors” may be ignored.

Fields:

OtherPolys_ID	*Primary key. Values = OTP1, OTP2, OTP3, … Values must be unique in database as a whole. Null values not permitted*
Type	*Term that categorizes the kind of the overlaying feature. Values must be defined in the Glossary table. Null values not permitted*
IdentityConfidence	*How confidently is this polygon identified as Type? Value is usually ‘certain’, ‘questionable’, or ‘unspecified’. Null values not permitted. Suggest setting default value to ‘certain’*
Label	*May be calculated from Type and IdentityConfidence. Allows for subscripts and special characters. Null values OK*
Symbol	*References an area fill symbol (background color + optional pattern) in the accompanying style file. Calculated from MapUnit. Null values OK*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*
Notes	*Free text for additional information specific to this feature. Null values OK*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*

Topology rules: None.

Overlay polygon boundaries will typically have complex relationship with lines in ContactsAndFaults: in part coincident, in part not coincident. In general, overlay polygon boundaries will not be stroked.

RepurposedSymbols (non-spatial table)

Line and point symbolization should follow the FGDC Digital Cartographic Standard for Geologic Map Symbolization (FGDC-STD-013-2006). If the FGDC Standard does not define a suitable symbol required for a geologic map, the Standard may be supplemented with custom symbols or with FGDC symbols that are “repurposed” for the map. Such repurposed symbols should be identified in this table, which becomes a required table if FGDC symbols are repurposed.

RepurposedSymbol_ID	*Primary key. Example values = RSY1, RSY2, RSY3, … Null values not permitted*
FgdcIdentifier	*Zero-padded identifier string from FGDC standard, for example, 01.01.03. Null values not permitted*
OldExplanation	*Explanatory text from FGDC standard for meaning of symbol, for example, “Contact—Identity and existence certain, location approximate’. Null values not permitted*
NewExplanation	*Explanation of usage of symbol in this map portrayal, for example, “Limit of tephra deposits from Holocene eruptions of Glacier Peak’. Null values not permitted*

Symbolization

Symbolization is a critical aspect of a geologic map. It illustrates the geologist’s interpretation and may depict (via color, type size, and other graphical elements) subtleties of interpretation and emphasis that are otherwise not obvious in the geodatabase. Creating an adequate symbolization of a geologic map database can be a significant amount of work, thus provision of an acceptable set of symbolization instructions is often a significant convenience to database users. For these reasons, we require that geologic-map databases include symbolization instructions for a preferred visualization.

Symbolization instructions may include a single ESRI .style file for all symbols (area, line, marker) used in the preferred visualization and an ESRI map composition (.mxd) file. Alternatively, authors may choose to use ESRI’s Cartographic

Representations to symbolize one or more map layers. For each feature class, values of either the Symbol attribute or the RuleID attribute should be non-null. At this time, a subset of the FGDC Standard's library of symbols is available as Cartographic Representations through ESRI's Geologic Mapping Template ("GMT", *http://resources.esri.com/mapTemplates/index.cfm?fa=codeGalleryDetails&scriptID=16317* or see the NCGMP09 Web site for any updated links or information). ESRI's GMT stores the symbols in feature classes organized according to the sections of the FGDC Standard. This organization is not compliant with NCGMP09 and we are working with ESRI on methods to facilitate use of the GMT representations within the NCGMP09 design.

For the convenience of users without access to an ArcGIS license, we also require provision of an ArcReader document (.pmf file), and descriptions of the symbolization in order for it to be replicated in other GISs (for example, for map-unit areas, the AreaFillRGB and AreaFillPatternDescription fields in the DescriptionOfMapUnits non-spatial table).

Line and point symbolization should follow the FGDC Digital Cartographic Standard for Geologic Map Symbolization (FGDC-STD-013-2006). These symbols are implemented in an ArcGIS style and associated font files created by staff at the Geological Survey of Canada (see *http://ngmdb.usgs.gov/Info/standards/NCGMP09/* for links and latest version). Note that to use this style it will be necessary to zero-pad the FGDC symbol identifiers so that each part of the identifier has a two- or three-character width: 1.1.3 becomes 01.01.03; 1.1.25 becomes 01.01.25. Where the FGDC Standard does not define a suitable symbol, the Standard may be supplemented with custom symbols or with FGDC symbols that are "repurposed" for the map. Such repurposed symbols should be identified in the RepurposedSymbols table, which is required if FGDC symbols have been repurposed.

Shapefile Versions Of The Geodatabase

We require that two shapefile versions of the geodatabase be provided: (1) a simple version, designed to permit ready symbolization and query without need to establish relates or joins to non-spatial tables, and without all the content of the full database and (2) an open version that uses well-documented file formats to supply as much of the database content as possible. Script ncgmp09_TranslateToShape.py (available at *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*) translates an NCGMP09-style geodatabase to both simple and open shapefile versions.

Simple Version

At a minimum, the simple shapefile version of the database must include shapefile equivalents of MapUnitPolys and ContactsAndFaults. Various other line and point-feature shapefiles from the GeologicMap feature dataset are optional additions. Most attribute data are included with every shape record, thus no related tables or joins are required to browse the data.

To create the MapUnitPolys shapefile, join DescriptionOfMapUnits (via the MapUnit field) and DataSources (via DataSourceID field) tables to the MapUnitPolys feature class. Map long field names from the geodatabase to short (10 characters or less), DBF-compatible names and export to a polygon shapefile. Delete the OBJECTID_ID, Source, and Notes fields from the DescriptionOfMapUnits and DataSources tables from the exported table (see Table 2). If the DescriptionOfMapUnits source field contains important information that is not conveyed by the MapUnitPolys source, consider updating the MapUnitPolys source. Field-name translation should be documented in an accompanying text file. Certain fields (for example, Text field in DescriptionOfMapUnits) are likely to be truncated to fit the 255-character limit for DBF fields; this is unfortunate, but acceptable.

To create the ContactsAndFaults shapefile, join Glossary (Type field joins to Term in Glossary) and DataSources (via the DataSourceID field) tables to the ContactsAndFaults feature class. Delete OBJECTID_ID, RuleID, Override, DataSourceID, Glossary_ID, Glossary DefinitionSourceID, and DefinitionSource Notes fields (Table 3). Map long field names from the geodatabase to short, DBF-compatible names and export to a line shapefile. Other feature classes may be exported to shapefiles following similar procedures.

Table 2. Fields in denormalized ESRI shapefile export of MapUnitPolys feature class. Fields from joined tables that are redundant or not applicable are shown with struck-out text (~~example~~). Note original field name column uses hyphens to improve readability, but the hyphens are not part of the field names.

Original field name	Short field name	Notes on usage
MapUnit-Polys_ID	MUnPol_ID	*Primary key. Example Values = MUP1, MUP2, MUP3, and so on. Values must be unique in database as a whole. Null values not permitted*
MapUnit	MapUnit	*Short plain-text identifier for the map unit. Example values: Qal, Tg, Kit, Trc3, and so on. Null values not permitted—a mapped polygon must have an assigned map unit. In order to avoid corruption of text strings in transformation between formats, only lower and upper case letters and numerals in* standard ASCII encoding *should be used in these identifier strings. Null values not permitted*
Identity-Confidence	IdeCon	*Term to express confidence that this polygon is correctly identified as MapUnit? Value is usually "certain", "questionable", or "unspecified". Suggest setting default value to 'certain'. Null values not permitted*
Label	Label	*Text string used to place label in map display; includes graphic elements such as special fonts and formatting for subscripts. For example, Triassic Newark Formation might be "<font=FGDCGeoAge>#n". Calculated from MapUnit//Label and Identity-Confidence: if IdentityConfidence = "low", then append "?" to MapUnit//Label. Allows for subscripts and special characters. Null values OK*
Symbol	Symbol	*References an area fill symbol (background color + optional pattern). Area fill symbols should be defined in an accompanying file. Null values OK*
Notes	Notes	*Free text for additional information specific to this polygon. Null values OK*
~~DataSourceID~~		~~*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted.*~~ **Flat file format includes the 'source' field text from DataSource table, remove foreign key from export**
~~Label~~		~~*Null values OK for units that do not appear on map or are not labeled, for example, headings, headnotes, water, glacier, some overlay units*~~ **Keep label field from polygon, remove duplicate from DMU table in flat file export**
Name	Name	*Boldface name in traditional DMU, identifies the unit within its hierarchical context. Examples: 'Chinle Formation', 'Shnabkaib Member'. These names should be verified in the U.S. Geologic Names Lexicon (GEOLEX); if your usage does not agree with GEOLEX's, notification should be submitted to the Lexicon Web site. Null values OK*
FullName	FullName	*Full name of unit, including identification of containing higher rank units, for example, 'Shnabkaib Member of Moenkopi Formation'. This is the text you would like to see as fly-out when cursor lingers over polygon in an electronic map display. See Lexicon-related note in "Name", above. Null values OK (for example, for headings, headnotes, geologic units not shown on map)*
Age	Age	*As shown in bold within parentheses in traditional DMU. Null values may be used for map units that inherit Age from a parent unit, or for headings, headnotes, or overlay units*
Description	Des	*Free-format text description of map unit. Commonly structured according to one or more accepted traditions (for example, lithology, thickness, color, weathering and outcrop characteristics, distinguishing features, genesis, age constraints) and terse. Allows markup (for example, HTML) specification of new paragraphs, superscripts and subscripts, and geologic-age font (sans-serif and with special characters). Null values OK*
HierarchyKey	HKey	*Has form nn-nn-nn, nnn-nnn, or similar. Numeric, left-padded with zeros, dash-delimited. Each HierarchyKey fragment of each row MUST be the same length to allow text-based sorting of the DMU entries. These strings are useful for resolving queries involving hierarchical relationships, for example, 'find all members of formation x', 'what is the parent unit of map unit y'. Null values not permitted*
ParagraphStyle	ParSty	*Values are Heading1st, Heading2nd, Heading3rd, Headnote, DMU1, DMU2, DMU3, or similar. Formatting associated with a paragraph style should be explained with a definition of the style in the glossary. Null values not permitted*

Original field name	Short field name	Notes on usage
AreaFillRGB	RGB	*{Red, Green, Blue} tuples that specify the color (for example, '255,255,255', '124,005,255') of area fill for symbolizing the unit. Use of consistent syntax is important to enable computer programs to read this field and display intended color. Each color value is an integer between 0 and 255, values are 0-padded so there are always 3 digits, color values are separated by commas with no space: NNN,NNN,NNN. Especially important to non-ESRI users unable to use the .style file. Null values OK (for example, headings, headnotes)*
AreaFillPattern-Description	PatDes	*Text description (for example,' random small red dashes') provided as a convenience for users who must recreate symbolization. Especially important to non-ESRI users unable to use the .style file. Null values OK (for example, headings, headnotes, unpatterned map units)*
~~Description-SourceID~~		~~*Foreign key to DataSources. Identifies source of DescriptionOfMapUnits entry. Null values not permitted*~~ **Remove from flat file export**.
General-Lithology	GenLit	*Term to categorize the map unit based on lithologic and genetic character, from NGMDB standard term list (Appendix A). Null values OK for headings and unmapped units*
General-Lithology-Confidence	GenLitCo	*Appropriateness of term for describing the map unit (Appendix A). Null values OK for headings and unmapped units*
Source	Source	*Plain-text short description to identify the data source, from MapUnitPolys.DataSource_ID join. If the DescriptionOfMapUnits source field contains important information that is not conveyed by the MapUnitPolys source, consider updating this source text with information from the DMU source as well. Null values not permitted*

Table 3. Fields in denormalized ESRI shapefile format for ContactsAndFaults. Fields from joined tables that are redundant or not applicable are show with struck-out text (~~example~~). Note original field name column uses hyphens to improve readability, but the hyphens are not part of the field names.

Original field name	Short field name	Notes on usage
ContactsAndFaults_ID	ConFau_ID	*Primary key for database record. Example values = COF1, COF2, … Values must be unique in database as a whole. Null values not permitted*
Type	Type	*Specifies the kind of feature represented by the line. Values could be, for example, 'contact', 'fault', 'waterline', 'glacier boundary', 'map boundary'. Values must be defined in Glossary. Null values not permitted*
IsConcealed	IsCon	*Values = 'N','Y'. This is a flag for contacts and faults covered by overlying map unit. Null values not permitted*
LocationConfidence-Meters	LocConMet	*Half-width in meters of positional uncertainty envelope; position is relative to other features in database. Data type = float. Recommend value of -9 if value is not available. Null values not permitted*
ExistenceConfidence	ExiCon	*Values = 'certain', 'questionable', 'unspecified'. Suggest setting default value = 'certain'. Null values not permitted*
IdentityConfidence	IdeCon	*Values: 'certain', 'questionable, 'unspecified". Suggest setting default value = 'certain'. Null values not permitted*
Symbol	Symbol	*References a symbol in the accompanying style file. Calculated from Type, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and expected map display scale. Null values OK*
~~RuleID~~		~~*If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*~~
~~Override~~		~~*If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section, below)*~~
Label	Label	*Can be used to store fault name, or human-readable name for a line feature. To group line segments into a specific structure trace, for example"San Andreas Fault", use Extended Attributes. Typically null*
Notes	Notes	*Free text for additional information specific to this feature. Null values OK*

Original field name	Short field name	Notes on usage
~~DataSourceID~~		~~*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*~~*. DataSources text corresponding to this key is included in export table*
~~Glossary_ID~~		~~*Primary Key. Example values = GLO1, GLO2, GLO3, … Null values not permitted*~~
~~Term~~		~~*Term — Plain-language word for a concept. Values must be unique within database as a whole. Example values: granite, foliation, syncline axis, contact, thrust fault, certain, low, fission track, K-Ar. Null values not permitted*~~ *Glossary Term field duplicates Type field, don't include both*
Definition	Definition	*Plain-language definition of ContactAndFault Type. Null values not permitted*
~~DefinitionSourceID~~		~~*Foreign key to DataSources. Identifies source of Definition. Null values not permitted*~~
Source	Source	*Plain-text short description to identify the data source from the ContactsAndFaults DataSourceID field joined to DataSources. If the Definition source information from the Glossary table adds important information, this source field text should be updated to include it. Null values not permitted*
~~Notes~~		~~*Notes on source, providing more complete description of processing or data acquisition procedure. Can include a full citation and (or) URL. Null values OK*~~

Open Version

The open shapefile version of the geodatabase consists of shapefile and DBF translations of all feature classes and non-spatial tables. Each feature class and non-spatial table is exported to a shapefile or DBF table as appropriate, with long field names translated to short (10 characters or less) DBF-compatible field names and the translation documented in an accompanying file. Fields more than 255 characters long are truncated, as necessitated by the DBF file format, but are also translated to delimited text files.

In the long term, we recommend that an application-independent, open interchange file format be adopted as an alternate data delivery mechanism. The IUGS Commission for Management and Application of Geoscience Information (CGI) is supporting development of an XML-based markup for geoscience information interchange (GeoSciML, *http://www.geosciml.org/*), which has the potential to be this format. The USGS and AASG participate in development of GeoSciML, and are testing it as an output format for NCGMP09.

Appendix A. Lithology and Confidence Terms for GeneralLithology

Much of the benefit from a defined database schema depends on use of clearly defined vocabularies. Users of geologic map databases are best served if some vocabularies, particularly lithology, are consistent from one database to another. These commonly are referred to as controlled-term vocabularies. Other vocabularies (for example, Type terms, ExtendedAttributes Properties) are uncontrolled vocabularies. Both controlled and uncontrolled terms should be defined in the Glossary table. General metadata should fully specify, under Supplemental Information, the sources and versions of all vocabularies used in the database.

GeneralLithology

Lithologic terms and definitions are here provided in an indented format for clarity. An accompanying spreadsheet (see *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*) also includes the Hierarchy Key to facilitate sorting. Documentation of this classification, including rationale for its development, is provided in Soller (2009; *http://pubs.usgs.gov/of/2009/1298/pdf/usgs_of2009-1298_soller4.pdf*); some terms and definitions in that classification were updated for this version of GeneralLithology (v. 1.1). The current version of this classification is maintained at the NCGMP09 Web site.

This classification is intended to characterize a map unit with a generalized category based on lithologic and genetic criteria; it applies to the map unit as a whole. The purpose of this scheme is to provide a basis for quickly integrating map data from different sources, and to convey to the public a simple, general sense of each map unit's lithology. Such a scheme cannot adequately address the immense variety of map units occurring on a national level, and we expect that other regionally specific map-unit integration schemes will also be developed that are more appropriate to local conditions. The appropriateness of a selected term for describing a map unit is specified by the GeneralLithologyConfidence field. This provides the map user with a useful qualifier term and indicates to the classification developer where revisions may be needed. Please refer to the GeneralLithology discussion in "Design Considerations", above.

GeneralLithology terms and definitions are:

- **Sedimentary material** -- An aggregation of particles deposited by gravity, air, water, or ice, or as accumulated by other natural agents operating at Earth's surface such as chemical precipitation or secretion by organisms. May include unconsolidated material (sediment) and (or) sedimentary rock. Does not here include sedimentary material directly deposited as a result of volcanic activity.
  - **Sediment** -- Unconsolidated material (sediment) composed of particles deposited by gravity, air, water, or ice, or as accumulated by other natural agents operating at Earth's surface such as chemical precipitation or secretion by organisms. Does not here include sedimentary material directly deposited as a result of volcanic activity.
    - **Clastic sediment** -- A sediment formed by the weathering and erosion of preexisting rocks or minerals; the eroded particles or "clasts" are transported and deposited by gravity, air, water, or ice.
      - **Sand and gravel of unspecified origin** -- A sediment composed mostly of sand and (or) gravel, formed by the weathering and erosion of preexisting rocks or minerals; the eroded particles or "clasts" are transported and deposited by gravity, air, water, or ice.
      - **Silt and clay of unspecified origin** -- A sediment composed mostly of silt and (or) clay, formed by the weathering and erosion of preexisting rocks or minerals; the eroded particles or "clasts" are transported and deposited by gravity, air, water, or ice.
      - **Alluvial sediment** -- Unconsolidated material deposited by a stream or other body of running water, as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope. Grain size varies from clay to gravel.
        - **Alluvial sediment, mostly coarse-grained** -- Unconsolidated material deposited by a stream or other body of running water, as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope. This sediment is mostly sand and gravel, but may contain some mud and (or) cobbles and boulders.
        - **Alluvial sediment, mostly fine-grained** -- Unconsolidated material deposited by a stream or other body of running water, as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope. This sediment is mostly silt and clay, but may contain some coarser material (for example, sand, gravel).
      - **Glacial till** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.
        - **Glacial till, mostly sandy** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of clay, silt, sand, gravel, and boulders ranging widely in size and shape. Relatively sandy in texture.
        - **Glacial till, mostly silty** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a

heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape. Relatively loamy (silty) in texture.
    - **Glacial till, mostly clayey** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape. Relatively clayey in texture.
- **Ice-contact and ice-marginal sediment** -- Mostly sand, silt, and gravel-sized particles or "clasts" derived from rock or preexisting sediment eroded and transported by glaciers. As the ice melted, this material was deposited by running water essentially in contact with glacial ice, or was transported and deposited by glacially fed streams. Includes sediment deposited into water bodies adjacent to the glacial ice margin.
    - **Ice-contact and ice-marginal sediment, mostly coarse-grained** -- Mostly sand and gravel-sized particles or "clasts," with lesser silt and clay, derived from rock or preexisting sediment eroded and transported by glaciers. As the ice melted, this material was deposited by running water essentially in contact with glacial ice, or was transported and deposited by glacially fed streams. Includes sediment deposited into water bodies adjacent to the glacial ice margin.
    - **Ice-contact and ice-marginal sediment, mostly fine-grained** -- Mostly silt and clay-sized particles or "clasts," with lesser sand and gravel, derived from rock or preexisting sediment eroded and transported by glaciers. As the ice melted, this material was deposited by running water essentially in contact with glacial ice, or was transported and deposited by glacially fed streams. Includes sediment deposited into water bodies adjacent to the glacial ice margin.
- **Eolian sediment** -- Silt- and sand-sized sediment deposited by wind.
    - **Dune sand** -- Mostly sand-sized sediment deposited by wind. Typically characterized by various dune landforms.
    - **Loess** -- Silty material deposited by winds near the glacial margin.
- **Lacustrine sediment** -- Mostly well sorted and well bedded material ranging in grain size from clay to gravel, deposited in perennial to intermittent lakes. Much of the sediment is derived from material eroded and transported by streams. Includes deposits of lake-marginal beaches and deltas.
    - **Lacustrine sediment, mostly coarse-grained** -- Mostly well-sorted and well-bedded material, generally sand- and gravel-sized with lesser silt and clay, deposited in perennial to intermittent lakes. Much of the sediment is derived from material eroded and transported by streams. Includes deposits of lake-marginal beaches and deltas.
    - **Lacustrine sediment, mostly fine-grained** -- Mostly well-sorted and well-bedded material, generally silt- and clay-sized with lesser sand and gravel, deposited in perennial to intermittent lakes. Much of the sediment is derived from material eroded and transported by streams. Includes deposits of lake-marginal beaches and deltas.
- **Playa sediment** -- Fine-grained sediment and evaporite salts deposited in ephemeral lakes in the centers of undrained basins. Includes material deposited in playas, mudflats, salt flats, and adjacent saline marshes. Generally interbedded with eolian sand and with lacustrine sediment deposited during wetter climatic periods; commonly intertongue upslope with sediment deposited by alluvial fans.
- **Coastal zone sediment** -- Mud and sandy sediment deposited in beach, barrier

island, nearshore marine deltaic, or in various low-energy shoreline (mud flat, tidal flat, sabka, algal flat) settings.

- **Coastal zone sediment, mostly coarser grained** -- Mostly sand-, silt-, and gravel-sized sediment deposited on beaches and dunes, and in shallow marine and related alluvial environments.
- **Coastal zone sediment, mostly fine-grained** -- Mostly clay- and silt-sized sediment deposited in lagoons, tidal flats, backbarriers, and coastal marshes.

- **Marine sediment** -- Mud and sandy sediment deposited in various marine settings. Sediment may originate from erosion of rocks and sediments on land, or from marine organisms (of carbonate or siliceous composition).
  - **Marine sediment, mostly coarser grained** -- Mud and sandy sediment derived from erosion or rocks and sediment on land, transport by streams, and deposition on marine deltas and plains. Sediment therefore is mostly siliceous in composition.
  - **Marine sediment, mostly fine-grained** – Mostly clay- and silt-sized sediment deposited in relatively deep, quiet water, far removed from areas where coarser grained clastic sediments are washed into the marine environment. Includes sediment derived from marine organisms.
- **Mass movement sediment** -- Formed by downslope transport of particles or "clasts" produced by weathering and breakdown of the underlying rock, sediment, and (or) soil. Composed of poorly sorted and poorly stratified material ranging in size from clay to boulders. Includes colluvium, landslides, talus, and rock avalanches.
  - **Colluvium and other widespread mass-movement sediment** -- Formed by relatively widespread and slow downslope transport of particles or "clasts" produced by weathering and breakdown of the underlying rock, sediment, and (or) soil. Composed of poorly sorted and poorly stratified material ranging in size from clay to boulders.
  - **Debris flows, landslides, and other localized mass-movement sediment** -- Formed by relatively localized downslope transport of particles or "clasts" produced by weathering and breakdown of the underlying rock, sediment, and (or) soil. Composed of poorly sorted and poorly stratified material ranging in size from clay to boulders. Commonly, the slopes on which this material occurs fail because of water, earthquake, or volcanic activity, and this material is then transported and deposited downslope. The speed of sediment transport ranges from rapid to imperceptible.

- **Residual material** -- Unconsolidated material presumed to have developed in place, by weathering of the underlying rock or sediment. Usually forms a relatively thin surface layer that conceals the unweathered or partly altered source material below, and is the material from which soils are formed.
- **Carbonate sediment** -- A sediment formed by the biotic or abiotic precipitation from aqueous solution of carbonates of calcium, magnesium, or iron; for example, limestone and dolomite.
- **Peat and muck** -- An unconsolidated material principally composed of plant remains, with lesser amounts of generally fine-grained clastic sediment. Deposited in a water-saturated environment such as a swamp, marsh, or bog. It is an early stage or rank in the development of coal.

- **Sedimentary rock** -- Consolidated material (rock) composed of particles deposited by gravity, air, water, or ice, or as accumulated by other natural agents operating at Earth's surface such as chemical precipitation or secretion by organisms. Does not here include sedimentary material directly deposited as a result of volcanic activity.

- **Clastic sedimentary rock** -- Sedimentary rock that is composed dominantly of particles or "clasts" derived by erosion, weathering, or mass-wasting of preexisting rock, and deposited by gravity, air, water, or ice.
    - **Conglomerate** -- Sedimentary rock that is composed dominantly of particles or "clasts" derived by erosion and weathering of preexisting rock, and containing more than 30 percent gravel-sized particles.
    - **Sandstone** -- Sedimentary rock that is composed dominantly of particles or "clasts" derived by erosion and weathering of preexisting rock, consisting mostly of sand-sized particles, with or without a fine-grained matrix of silt or clay.
    - **Mostly sandstone** -- This area is underlain by sequences of various sedimentary rocks that, for this generalized map depiction, are too complex to be shown separately. Mostly sandstone, interbedded with other sedimentary rocks which locally may include conglomerate and finer grained clastics (mudrock), carbonates, and (or) coal.
    - **Sandstone and mudstone** -- Approximately equal (or unspecified) proportion of sandstone and mudstone (which includes shale and siltstone).
    - **Mudstone** -- Sedimentary rock that is composed dominantly of particles or "clasts" derived by erosion and weathering of preexisting rock, consisting mostly of mud (silt- and clay-sized particles). Includes shale and siltstone.
    - **Mostly mudstone** -- This area is underlain by sequences of various sedimentary rocks that, for this generalized map depiction, are too complex to be shown separately. Mostly mudstone, interbedded with other sedimentary rocks which locally may include coarser grained clastics (sandstone, conglomerate), carbonates, and (or) coal.
- **Carbonate rock** -- A sedimentary rock such as limestone or dolomite, consisting chiefly of carbonate minerals.
- **Mostly carbonate rock** -- This area is underlain by sequences of various sedimentary rocks that, for this generalized map depiction, are too complex to be shown separately. Mostly carbonate rock, interbedded with clastic sedimentary rock.
- **Evaporitic rock** -- Sedimentary rock composed primarily of minerals produced by evaporation of a saline solution. Examples include gypsum, anhydrite, other diverse sulfates, halite (rock salt), primary dolomite, and various nitrates and borates.
- **Iron-rich sedimentary rock** -- Sedimentary rock in which at least 50 percent of the observed minerals are iron-bearing (hematite, magnetite, limonite-group, siderite, iron sulfides).
- **Coal and lignite** -- Organic-rich sedimentary rock formed from the compaction and alteration of plant remains. Coal is a consolidated, hard black organic rock, whereas lignite is a semiconsolidated brown to black, earthy material, which may contain large particles of recognizable plant parts and tends to crack upon drying.

- **Sedimentary and extrusive igneous material** -- This area is underlain either by (1) sedimentary rock and (or) unconsolidated material (sediment) and by extrusive igneous material (volcanic rock and (or) sediment) or (2) by volcanic rock and (or) sediment and by such material after erosion and redeposition.
- **Igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma).
    - **Extrusive igneous material** -- Molten material that was erupted onto the surface of the Earth, fusing into rock or remaining as unconsolidated particles. Includes lava flows and pyroclastic material such as volcanic ash.
        - **Volcaniclastic (fragmental) material** -- Rock and unconsolidated material consisting of particles or "clasts" that were formed by volcanic explosion or aerial expulsion from a volcanic vent.
            - **Pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano. This material moves downslope commonly in chaotic flows. Once deposited, the

material may deform and weld together because of the intense heat and the weight of the overlying material.

- **Felsic-composition pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano. This material moves downslope commonly in chaotic flows. Once deposited, the material may deform and weld together because of the intense heat and the weight of the overlying material. Composed of light-colored rocks (for example, rhyolite, dacite, trachyte, latite) which, because of their high-silica content and resulting high viscosity, tend to erupt explosively.
- **Intermediate-composition pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano. This material moves downslope commonly in chaotic flows. Once deposited, the material may deform and weld together because of the intense heat and the weight of the overlying material. Composed of rocks (for example, andesite) intermediate in color and mineral composition between felsic and mafic rocks. Andesite magma commonly erupts from stratovolcanoes as thick lava flows but also can generate strong explosive eruptions to form pyroclastic flows.
- **Mafic-composition pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano. This material moves downslope commonly in chaotic flows. Once deposited, the material may deform and weld together because of the intense heat and the weight of the overlying material. Composed of dark-colored rocks (for example, basalt) which, because of their low-silica content and resulting low viscosity, tend to erupt gently as lava flows rather than more forcefully as pyroclastic flows.

- **Air-fall tephra** -- Fragments of volcanic rock and lava, of various sizes, are known as “tephra.” This material is carried into the air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. At some distance from a volcano, the deposit is known as volcanic ash.
    - **Felsic-composition air-fall tephra** -- Fragments of volcanic rock and lava, of various sizes, are known as “tephra.” This material is carried into the air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. Composed of light-colored rocks (for example, rhyolite, dacite, trachyte, latite) which, because of their high-silica content and resulting high viscosity, tend to erupt explosively, readily forming pumice and volcanic ash.
    - **Intermediate-composition air-fall tephra** -- Fragments of volcanic rock and lava, of various sizes, are known as “tephra.” This material is carried into the air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. Composed of rocks (for example, andesite) intermediate in color and mineral composition between felsic and mafic rocks. Andesite magma commonly erupts from stratovolcanoes as thick lava flows but also can generate strong explosive eruptions, readily forming pumice and volcanic ash.
    - **Mafic-composition air-fall tephra** -- Fragments of volcanic rock and lava, of various sizes, are known as “tephra.” This material is carried into the

air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. Composed of dark-colored rocks (for example, basalt) which, because of their low-silica content and resulting low viscosity, tend to erupt gently as lava flows rather than more forcefully, and so these deposits are uncommon.

    - **Lava flows** -- A lateral, surficial outpouring of molten lava from a vent or a fissure, and the solidified body of rock that forms when it cools. Composed generally of fine-grained, dark-colored rocks (for example, basalt), and tends to form extensive sheets with generally low relief except in the vent areas where cinder cones or shield volcanoes may form. Includes basaltic shield volcanoes, which may become very large (for example, Hawaii).
        - **Felsic-composition lava flows** -- A lateral, surficial outpouring of molten lava from a vent or a fissure, and the solidified body of rock that forms when it cools. Composed of fine-grained, light-colored rocks which, because of their high-silica content and resulting high viscosity, tend to erupt explosively, and so these deposits are uncommon. Includes rhyolitic, dacitic, trachytic, and latitic rock.
        - **Intermediate-composition lava flows** -- A lateral, surficial outpouring of molten lava from a vent or a fissure, and the solidified body of rock that forms when it cools. Composed of fine-grained rocks intermediate in color and mineral composition between felsic and mafic rocks, and commonly erupts from stratovolcanoes as thick lava flows. Includes andesitic rock.
        - **Mafic-composition lava flows** -- A lateral, surficial outpouring of molten lava from a vent or a fissure, and the solidified body of rock that forms when it cools. Composed of fine-grained, dark-colored rocks, and tends to form extensive sheets with generally low relief. Includes basaltic shield volcanoes, which may become very large (for example, Hawaii). Includes basaltic rock.
- **Intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma), forming below the Earth's surface.
    - **Coarse-grained intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye.
        - **Coarse-grained, felsic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Composed mostly of light-colored minerals. Includes granitic, syenitic, and monzonitic rock.
        - **Coarse-grained, intermediate-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Intermediate in color and mineral composition between felsic and mafic igneous rock. Includes dioritic rock.
        - **Coarse-grained, mafic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Composed mostly of dark-colored minerals. Includes gabbroic rock.
        - **Ultramafic intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at some depth beneath the Earth's

surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Composed mostly of mafic minerals, for example, monomineralic rocks composed of hypersthene, augite, or olivine.

        - **Fine-grained intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they occur as tabular dikes or sills.
            - **Fine-grained, felsic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they occur as tabular dikes or sills. Composed mostly of light-colored minerals. Includes rhyolitic, dacitic, trachytic, and latitic rock.
            - **Fine-grained, intermediate-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they occur as tabular dikes or sills. Intermediate in color and mineral composition between felsic and mafic igneous rock. Includes andesitic rock.
            - **Fine-grained, mafic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they occur as tabular dikes or sills. Composed mostly of dark-colored minerals. Includes basaltic rock.
        - **Exotic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (that is, magma), forming below the Earth's surface and having exotic mineralogical, textural, or field setting characteristics. These rocks typically are dark colored with abundant phenocrysts. Includes kimberlite, lamprophyre, lamproite, and foiditic rocks.
- **Igneous and metamorphic rock** -- Consists of coarse-grained intrusive igneous rocks and generally medium to high grade metamorphic rocks.
- **Metamorphic rock** -- A rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust.
    - **Regional metamorphic rock, of unspecified origin** -- A rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked regional changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust. In this area, the origin of the preexisting rock is mixed (for example, igneous and sedimentary) or is not known.
        - **Medium and high-grade regional metamorphic rock, of unspecified origin** -- A rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to relatively intense regional changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust. In this area, the origin of the preexisting rock is mixed (for example, igneous and sedimentary) or is not known. Includes rocks such as amphibolite, granulite, schist, and gneiss.
        - **Contact-metamorphic rock** -- Rock that originated by local processes of thermal metamorphism, genetically related to the intrusion and extrusion of magmas and taking place in rocks at or near their contact with a body of igneous rock. Metamorphic changes are effected by the heat and fluids emanating from the magma and by some deformation because of emplacement of the igneous mass.
        - **Deformation-related metamorphic rock** -- A rock derived from preexisting rocks by

mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment. Generally forms in narrow, planar zones of local deformation (for example, along faults) and characterized by foliation or alignment of mineral grains. Includes mylonite.

- **Metasedimentary rock** -- A rock derived from preexisting sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust.
    - **Slate and phyllite, of sedimentary rock origin** -- A fine-grained rock derived from preexisting sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust. Includes phyllite and slate, which is a compact, fine-grained rock that possesses strong cleavage and hence can be split into slabs and thin plates. Mostly formed from fine-grained material such as mudstone.
    - **Schist and gneiss, of sedimentary rock origin** -- A foliated rock derived from preexisting sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust. Includes schist (characterized by such strong foliation or alignment of minerals that it readily splits into flakes or slabs) and gneiss (characterized by alternating, irregular bands of different mineral composition). Mostly formed from fine-grained material such as mudstone.
    - **Marble** -- A rock derived from preexisting (commonly carbonate) sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust. Characterized by recrystallization of the carbonate minerals in the source rock.
    - **Quartzite** -- A rock derived from preexisting (commonly sandstone) sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust. Characterized by recrystallization of quartz in the source rock.
- **Metaigneous rock** -- A rock derived from preexisting igneous rocks (mostly extrusive in origin) by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust. Mafic and ultramafic schists and gneisses are common.

- **Other materials:**
    - **Rock and sediment** -- Various rocks and sediment, not differentiated.
    - **Rock** -- Various rock types, not differentiated.
    - **"Made" or human-engineered land** -- Modern, unconsolidated material known to have human-related origin.
    - **Water or ice**
    - **Unmapped area**

These definitions were adapted from a variety of published and unpublished works, including:

Blatt, Harvey, Tracy, R.J., and Owens, B.E., 2006, Petrology – Igneous, sedimentary, and metamorphic, 3rd ed.: W.H. Freeman and Company, New York, 530 p.

Hyndman, D.W., 1985, Petrology of igneous and metamorphic rocks, 2nd ed.: McGraw-Hill, Inc., New York, 576 p.

Neuendorf, K.K.E., Mehl, J.P., Jr., and Jackson, J.A., 2005, Glossary of geology, 5th ed.: American Geological Institute, Alexandria, VA., 779 p.

North American Geologic Map Data Model Steering Committee Science Language Technical Team, 2004, Report on Progress to Develop a North American Science-Language Standard for Digital Geologic-Map Databases, *in* Soller, D.R., ed., Digital Mapping Techniques '04 -- Workshop Proceedings: U.S. Geological Survey Open-File Report 2004-1451, p. 85-94 and 4 appendices containing the science terminologies, *http://pubs.usgs.gov/of/2004/1451/nadm/*.

National Geologic Map Database Project, 2007, Science vocabulary to support the National Geologic Map Database project: Lithology terms: U.S. Geological Survey unpublished document, 218 p.

Soller, D.R., and Reheis, M.C., compilers, 2004, Surficial materials in the conterminous United States: U.S. Geological Survey Open-File Report 03-275, scale 1:5,000,000, *http://pubs.usgs.gov/of/2003/of03-275/*.

USGS Photo glossary of volcanic terms, 2008, USGS Volcano Hazards Program Web site, *http://volcanoes.usgs.gov/images/pglossary/index.php*.

GeneralLithologyConfidence

Term	Definition
High	The term and definition adequately characterize the overall lithologic nature of rocks and sediments in the map unit. Regarding the subjective term "adequately characterize", we refer to context and objectives of this classification as described in the documentation.
Medium	The term and definition generally characterize the overall lithology of the map unit, but there are one or more significant minor lithologies that are not adequately described by the selected term.
Low	The overall lithology of this map unit is not adequately classifiable using this list of terms and definitions, but the term selected is the best available. Or this map unit is insufficiently known to confidently assign a GeneralLithology term.

NOTE: Please refer to the introductory note of this appendix, particularly the scope and intent, before assigning confidence values. We intend to use the confidence information to evaluate and revise GeneralLithology.

Appendix B. Optional Elements

Some parts of a geologic map publication may, if present, be encoded as image files (for example, .pdf, .ps, .tiff) or may, at the option of the publisher, be encoded within the geodatabase. We also define several non-spatial tables (ExtendedAttributes, GeologicEvents, and StandardLithology) that some map publishers may find useful. These are *optional elements*.

We expect that with further experience it may eventually be desirable to require that cross sections and Correlation of Map Units diagrams be encoded in the geodatabase.

Cross Sections (feature datasets)

Cross sections should be identified as cross-section A, cross-section B, cross-section C, and so on, abbreviated as CSA, CSB, CSC in the dataset and feature class names. Each cross section exists in a separate map-space, and thus requires a separate feature dataset for each cross section. For each cross section there are, at a minimum, two feature classes:

CSAContactsAndFaults	*(primary key is CSAContactsAndFaults_ID, values = CSACOF1, CSACOF2, …)*
CSAMapUnitPolys	*(primary key is CSAMapUnitPolys_ID, values = CSAMUP1, CSAMUP2, …)*

Field names, data types, usage, and topology rules for these feature classes are identical with those for ContactsAndFaults and MapUnitPolys. If lines that don't participate in MapUnit topology or point-based data are depicted on the cross-section, the appropriate feature classes (for example, CSAGeologicLines, CSAOrientationPoints) should be created.

Correlation of Map Units (feature dataset)

The Correlation of Map Units (CMU) diagram found on many geologic maps can be encoded as a feature dataset in a geodatabase. Doing so makes it easier to match symbolization of the CMU to that of the map and stores the information in the CMU in a fashion that is (slightly) more queryable than storing the CMU as a simple image. Two feature classes are necessary and a third (CMUText) will almost always be needed. If map units are depicted as point features an additional feature class is needed.

Note that inclusion of a CorrelationOfMapUnits diagram in a map report is NOT optional. Encoding the CMU as GIS features is optional.

CMUMapUnitPolys (polygon feature class)

Fields:

CMUMapUnitPolys_ID	*Primary key. Example values = CMUMUP1, CMUMUP2, CMUMUP3, … Null values not permitted*
MapUnit	*Foreign key to DescriptionOfMapUnits. Null values not permitted*
Label	*Value = MapUnit//Label. Null values OK*
Symbol	*References a symbol in accompanying style file. Null values OK*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section)*

Values for Symbol and Label are calculated with reference to DescriptionOfMapUnits. Ghost boxes (for example, protolith of a metamorphic unit) may be shown as MapUnitPolys with Symbol = 'blank'. Or the box outline alone can be stored in CMULines.

CMULines (line feature class)

Fields:

CMULines_ID	*Values are CMULIN1, CMULIN2, CMULIN3, … Null values not permitted*
Type	*Term to classify meaning of lines. Example values = 'contact', 'ghost contact', 'CMU leader', 'CMU rule', 'CMU bracket', or '<MapUnit> line'. Values must be defined in Glossary. Null values not permitted*
Symbol	*References a symbol in accompanying style file. Null values OK*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section)*

CMUText (annotation feature class)

Fields:

CMUText_ID	*Primary key. Example values = CMUTEX1, CMUTEX2, CMUTEX3, … Null values not permitted*
ParagraphStyle	*Null values not permitted*
Text	*Text to display*
Additional fields as implemented by GIS software	

Annotation text and annotation attributes, including font, font size, font effects, and text angle, are stored in default fields of the annotation feature class. Values for font, font size, and font effects can be calculated from ParagraphStyle.

CMUPoints (point feature class)

Fields:

CMUPoints_ID	*Primary key. Example values = CMUPNT1, CMUPNT2, CMUPNT3, … Null values not permitted*
Type	*Values are '<MapUnit> point'. Values must be defined in Glossary. Null values not permitted*
Symbol	*Null values OK*
Label	*Text string to display in association with symbol at this point*
RuleID	*Data type = integer. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section)*
Override	*Data type = blob. If Cartographic Representations are used, this field is required; otherwise it is not included in the table (see* Symbolization *section)*

ExtendedAttributes (non-spatial table)

The ExtendedAttributes table provides a general structure for linking attributes of any sort with any data item (identified table row) in the database.

Fields:

ExtendedAttributes_ID	*Primary key. Example values = EXA1, EXA2, EXA3, … Null values not permitted*
OwnerTable	*Full name of table that contains owning element, for example, DescriptionOfMapUnits, or OverlayPolys. May be any table in the database. Null values not permitted*
OwnerID	*Foreign key to table specified by the OwnerTable value. If Owner_ID record is deleted, associated extended attribute should be deleted (cascade delete). Convention is that this Foreign key will link to the TableName_ID field in the OwnerTable. Null values not permitted*
Property	*Name of property specified by this attribute or relationship between Owner and ValueLinkID items. Values defined in Glossary or external glossary; we strongly recommend Glossary definitions of all properties used in the ExtendedAttributes table. Definition of property should include explanation of formatting and units used to specify property values. Null values not permitted*
PropertyValue	*String, could be number (+ measurement unit) or defined term. Not closed. Data-entry tool might enforce consistency between PropertyValue and Property (such that Property=thickness does not have PropertyValue=fine-grained). NGMDB or individual projects might choose to supply Property | PropertyValues lists. Numeric values (for instance, 546.81 yards) are not defined in Glossary. If null, ValueLinkID must be non-null*
ValueLinkID	*Foreign key to data instance that specifies property value. For example, GrainSizeAnalyses_3. Or a link to another ExtendedAttributes record (for example, this thing overlies / succeeds / is-a-part-of another thing). Null values OK. If null, PropertyValue must be non-null, and vice-versa. Definition of Property must specify table to which the ValueLinkID is a foreign foreign key. If null, PropertyValue must be non-null*
Qualifier	*Expresses variability or extent of PropertyValue. Must be defined in Glossary or an external glossary. Null values OK*
Notes	*Free text. Null values OK*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Some example ExtendedAttributes records:

Extended-Attribute_ID	OwnerTable	OwnerID	Property	Property-Value	Value-LinkID	Qualifier	Notes	Data-SourceID
EA01650	Description-OfMapUnits	DMU3	Permeability	Low		Typical	Rock is full of alteration clays	DS2140
EA01654	Description-OfMapUnits	DMU3	Permeability	High		Rare		DS0001
EA01680	Description-OfMapUnits	DMU27	Metamorphic Grade	Low		Uncommon		DS0364
EA0162476	Description-OfMapUnits	DMU27	Metamorphic Grade	Medium		Typical		DS2069
EA01636	Description-OfMapUnits	DMU27	Metamorphic Age	Early Proterozoic		Probable		DS2106
EA01639	Description-OfMapUnits	DMU27	Metamorphic Age	Middle Cretaceous		Possible		DS045
EA016289	GeologicEvents	SlipEvent1	Displacement	4 km				DS1045
EA016233	GeologicEvents	SlipEvent1	Displacement-Type	Right-lateral strike slip				DS1130
EA016123	GeologicEvents	SlipEvent1	Successor		GE2466			DS1205
EA0160978	GeologicEvents	GE2466	Displacement	200 km				DS1135
EA0167032	GeologicEvents	GE2466	Displacement-Type	Right-lateral strike slip				DS0980
EA016086	Description-OfMapUnits	Txt	Permeability	Low			Rock is full of alteration clays	DS8625
EA016146	MapUnitPolys	Txt37a	Note				Big outcrop, good place for a quarry	DS2586
EA016826	Contacts-AndFaults	COF22	Has Photograph	Photo2008-11-12b				DS2640
EA016926	Contacts-AndFaults	COF22	Contact Character	Gradational				DS3656

ExtendedAttributes uses a pattern that associates a data item identified by ‘OwnerTable/OwnerID’ with a property-value pair. The property is identified by the value in the ‘Property’ field, and the property value is specified by the ‘PropertyValue’ or ‘ValueLinkID’. PropertyValue is used when the value can be represented by a single string or number. For property values that are themselves database rows, the ValueLinkID is the identifier for the database row that contains the value. Because there is no separate PropertyValueTable field, the identifier in ValueLinkID must convey the table that contains the linked data using the convention that the first part of the identifier is a table identifier. In addition, each attribute assignment may have a qualifier, may have notes related to the attribute value, and has an identified data source. The Qualifier is an optional attribute used to express quality, frequency, or intensity; vocabulary used in this field must be explained by corresponding Glossary table entries.

Data engineers will recognize this as the fundamental subject-predicate-object pattern, analogous to an RDF triple, with the addition of metadata for each statement. This data structure could be used to express everything in the database, but its use requires creation of database views. It is included here to provide a mechanism to add content that may be sparse (available for only a few of many possible items), or attributes that may have multiple values (many to many relationships). For data that cannot be represented using the other NCGMP09 database tables, the map author must decide whether these data are essential and if so, whether these data should be stored in ExtendedAttributes or in a new datatype-specific table. We anticipate that best-practice recommendations will emerge for particular kinds of data.

If normalized data are to be recoverable from the ExtendedAttributes data structure, each of the extended attributes instances must represent a single fact. For example, to represent a slip displacement event in a sequence of displacements on a complex fault or fault segment: “San Andreas Slip Event 1, Displacement 4 km right lateral strike slip” is composed of several facts: 1. SanAndreasFault has GeologicEvent xxxx; 2. GeologicEvent xxxx has SuccessorEvent = GeologicEvent yyyy (if there is a slipEvent2); 3. GeologicEvent xxxx has displacementMagnitude_m = 4000; 4. GeologicEvent xxxx has displacementType = ‘Right Lateral Strike Slip’. The GeologicEvent xxxx age value is the time bracket for the slip event. ‘San Andreas fault’ might be a concept in the Glossary that is associated with many individual fault segments in ContactsAndFaults feature class through other ExtendedAttributes links. Each of these facts would be a separate row in the ExtendedAttributes table.

The OwnerID in ExtendedAttributes is a foreign key that links to a data instance in any table, for example, DescriptionOfMapUnits, Glossary (for named faults that are 'supersets' of elements in the ContactsAndFaults feature class), MapUnitPolys for description of individual polygons, or GeologicEvents to describe a displacement event (if logic above is followed) or to add additional process and environmental information associated with an event. Map units should be referenced by DescriptionOfMapUnits_ID, not MapUnit. This contrasts with use of MapUnit as foreign key to the DescriptionOfMapUnits table in other parts of the geodatabase; the alternate convention is adopted here for consistency with references from ExtendedAttributes to other database tables. The 'OwnerTable' attribute is the name of the table that OwnerID references. We expect that explicit identification of OwnerTable will speed searches that otherwise would have to reference the entire world of _ID values within the geodatabase. The same performance issue is raised by the ValueLinkID property, but in this case the Glossary definition of the ExtendedAttribute property should specify the table that contains the linked values.

ValueLinkID allows 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 ExtendedAttributes to represent many kinds of semantic relationships between features in the geodatabase. 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. The ExtendedAttributes Property in this case specifies a relationship type.

GeologicEvents (non-spatial table)

Geologic ages are assigned by association with an event that is recorded in the rock record. Each event has an assigned age, specified either numerically or using a named era from a stratigraphic time scale.

Fields:

GeologicEvents_ID	*Primary key for event in this database. Example values = GEE1, GEE2, GEE3 ... Required*
Event	*This is the geologic process responsible for the observed, dateable feature in the rock record that is the basis for the age assignment. Example values: deposition, metamorphism, slipEvent1, and so on. Required. Foreign key to Glossary or vocabulary authority cited in dataset metadata. Event vocabularies maintained at the CGI Website (https://www.seegrid.csiro.au/wiki/bin/view/CGIModel/ConceptDefinitionsTG) are recommended*
AgeDisplay	*Formatted text that conveys the age assignment to a human reader, analogous to the Age attribute in the DMU table. Required*
AgeYoungerTerm	*Younger bound of interval for age of geologic event. Specified by a named time ordinal era from a stratigraphic time scale that is specified in the dataset metadata. Required if no numeric age provided*
AgeOlderTerm	*Older bound of interval for age of geologic event. Specified by a named time ordinal era from a stratigraphic time scale that is specified in the dataset metadata. Required if no numeric age provided*
TimeScale	*Name of a geologic time scale in which the age terms are defined. Various time scales may be used in a single data set, for example, ICS 2008, North American Land Mammal Stages 2005. Required if age terms are used*
AgeYoungerValue	*Data type = float. Number that specifies the younger bound of the interval for the age assignment. Use of numeric age range boundaries makes for simpler geologic age query resolution. Units used for numeric age assignment should be consistent within the database and the units should be specified in the Notes field. Required if no age term provided*
AgeOlderValue	*Data type = float. Number that specifies the older bound of the interval for the age assignment. Use of numeric age range boundaries makes for simpler geologic age query resolution. Units used for numeric age assignment should be consistent within the database and the units should be specified in the Notes field. Required if no age term provided*
Notes	*Free text, any additional information on this event or age assignment. Null values OK*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Some example GeologicEvents records:

Geologic-Events_ID	Event	AgeDisplay	Age-Younger-Term	Age-Older-Term	Age-Younger-Value	Age-Older-Value	Notes	Data-SourcesID
GE00001	FaultSlip	Early Miocene	Early Miocene	Early Miocene	20	22		DS26904
GE00022	FaultSlip	Pliocene to Quaternary	Quaternary	Pliocene	0	4		DS62016
GE2465	Deposition of Tvt	Miocene Deposition	Miocene	Miocene	8	22		DS105
GE23609	Laramide orogeny	Laramide age	Early Eocene	Cenoma-nian	40	80		DS20656

The GeologicEvents table allows explicit representation of complex histories and non-simple ages. Geologic events may be associated with multiple processes and environments (for example, depositional environments) through extended attributes. This content is required for compatibility with GeoSciML. AgeYoungerValue and AgeOlderValue are numeric and represent ranges or bounds on the 2-sigma uncertainty envelop on a measured numeric age, unless otherwise specified in the Notes field for the age.

There are four ways to represent an event in the history of a map unit: (1) the Age field of table DescriptionOfMapUnits, by convention this field has limited age resolution and can only represent the dominant event in the history of the unit; (2) in the Description field of table DescriptionOfMapUnits; (3) in the table ExtendedAttributes (property=MinimumAge, propertyValue=Maastrichtian); (4) this GeologicEvents table, with link via ExtendedAttributes table (property = preferredAge, ValueLinkID = GEE13). For ages of other features (for example, faults, single map-unit polygons) methods 3 and 4 are applicable, as is recording the age in the Notes field of the appropriate record(s) of the relevant spatial feature class.

We provide multiple options to record geologic ages because (a) we are not sure which option is best (and hope that in a short time best practice recommendations will emerge) and (b) we think it is likely that the best option depends on the quality and quantity of age information to be recorded.

StandardLithology (non-spatial table)

StandardLithology provides a simple structure for describing the various constituents that occur in geologic map units. It can be used to extend and supplement the unstructured free text descriptions and GeneralLithology terms found in the DescriptionOfMapUnits table.

The StandardLithology table represents the lithologic composition of map units by associating with the unit one or more lithology categories from the CGI SimpleLithology controlled vocabulary (*https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG*; see discussion in GeneralLithology above). Description of a single map unit may span several rows in this table. This allows description of multipart (spatially variable, interbedded, block-in-matrix) units with quantitative or qualitative description of the relative abundance of each component. Each associated lithology category has a part type that indicates how the rock type occurs within the unit (veins, layers, stratigraphic part, interbedded, inclusions, blocks…) and a proportion (either a qualitative term or numeric value).

Fields:

StandardLithology ID	*Primary key. Example values = STL1, STL2, STL3, … Null values not permitted*
MapUnit	*Unit abbreviation, foreign key to DescriptionOfMapUnits. Null values not permitted*
PartType	*Domain is CGI GeologicUnitPartRole vocabulary (https://www.seegrid.csiro.au/wiki/bin/view/CGIModel/ConceptDefinitionsTG). Terms used should be included in the Glossary, along with their URI. Use 'Not available' if information is not available*
Lithology	*Domain is CGI SimpleLithology vocabulary (see URL above). Values used should be defined in Glossary, along with their URI. Null values not permitted*
ProportionTerm	*Domain is CGI ProportionTerm list (see URL above). Users may wish to restrict this list of 10 terms to a shorter, less expressive but easier to use list (for example, see discussion, below). Values of ProportionTerm must be defined in the Glossary. Either ProportionTerm or ProportionValue should be non-null. Null values allowed*
ProportionValue	*Data type = float. Range 0–1.0. Must not sum to more than 1.0 for a given MapUnit. Either ProportionValue or ProportionTerm should be non-null. Null values allowed.*

ScientificConfidence	*Values = 'std', 'low'. Default value = 'std'. Value of 'low' indicates either that the assignment of the constituent to a lithology category from the controlled vocabulary is problematic, or that the proportion is poorly constrained. Null values not permitted*
DataSourceID	*Foreign key to DataSources. Identifies source of StandardLithology description. Null values not permitted*

Regarding ProportionTerm, the CGI list is recommended. But for parsing certain map descriptions into a controlled term list, especially those already compiled and published, a simpler list whose definitions are less precise may be found more appropriate. This is particularly the case where the percentage proportions, especially among the dominant lithologic constituents, cannot readily be determined. We provide this alternative list, and request comment on proportion term lists and definitions:

- all – the lithology constitutes all of the map unit
- major – lithology is a major or significant component of the map unit
- minor – lithology is a minor or relatively insignificant component of the map unit
- trace – lithology is present, but is a very small component of the map unit.

Below are examples of StandardLithology data. Field names are at the top of each column and each row represents a separate data instance. Use ProportionTerm or ProportionValue as appropriate; we recommend that the ProportionTerm be included for all entries. Both may not be null in a single record. ProportionValue terms are fractional values between 0.0 and 1.0 and for a single map unit should sum to 1.0 or less. If you generate StandardLithology records by interpreting map-unit descriptions in an existing map or database, set DataSourceID to point to an entry in the DataSources table, such as DAS2, Source = 'Smith and others, USGS Map I-37, interpreted by <your-name>' or similar.

StandardLithology_ID	MapUnit	PartType	Lithology	ProportionTerm	ProportionValue
STL26	Tx	beds	Sandstone	Dominant	
STL327	Tx	stratigraphic part	Siltstone	Minor	
STL579	Tx	stratigraphic part	Tuff	Minor	
STL264	Txt	beds	Tuff	Dominant	
STL265	Kit	whole	Tonalite	Dominant	
STL266	KJz	beds	Limestone	Dominant	.55
STL770	KJz	beds	Mudstone	Subordinate	.45

Appendix C. Building a Compliant Database

Note to readers: The following section is, of necessity, incomplete pending finalization of the database design. When the design is finalized, we expect to flesh this section out with further advice on how to construct compliant databases.

Empty compliant databases into which data can be imported or created can be built from scratch using the specification in this document, by running script ncgmp09_CreateDatabase.py (available at *http://ngmdb.usgs.gov/Info/standards/NCGMP09/*), by copying an empty geodatabase template, or by exporting the design (without data) from a template database as an ESRI XML-workspace file and then importing the XML file and adjusting the spatial references as necessary.

The production of a compliant database could be assisted by a number of custom tools and scripts. For example, we imagine tools to automate the population of the ChangeLog table and to calculate symbol field values (line symbols, for instance, reflect values in the Type, TypeModifier, IsConcealed, LocationConfidenceMeters, ExistenceConfidence, and IdentityConfidence fields as well as the output map scale). Script ncgmp09_ValidateDatabase.py checks the names of feature datasets, feature classes, tables, and fields, checks data types, and finds missing Glossary entries, undefined map units, and so on. We encourage discussion and collaboration to define and write tools and scripts.

Additional database elements

Construction of compliant databases will be facilitated by the creation of an additional point feature classes and a non-spatial table.

MapUnitPoints (point feature class, optional)

Some map producers generate the MapUnitPolys feature class from the ContactsAndFaults feature class and a feature class of 'label' points that holds the attributes associated with the polygons. This workflow utilizes the Feature to Polygon tool in the Data Management toolbox. A MapUnitPoints feature class facilitates this workflow. Note that the ID field in this feature class should be MapUnitPolys_ID.

Most map producers will find it easier to attach correct symbol values to polygon features if they relate MapUnitPoints to the DescriptionOfMapUnits table, via the MapUnit fields, and calculate MapUnitPoints.Symbol = DescriptionOfMapUnits. Symbol.

ChangeLog (non-spatial table, optional)

This table maintains information about updates to information contained in the database and is essential for documentation of the provenance of data from another source that are modified in the course of creating a new geologic map database. Each record records changes to a single database row, with old value, new value, and (if desired) the reason for a change in a NOTES field. One ChangeLog entry can record simultaneous changes to values in several fields of a single record. All fields except Notes could be populated automatically by code that pulls the relevant information from the operating system and attribute table upon editing of a data record. We hope to provide such a script in the future. Changes to feature geometry (for example, moving a vertex) are recorded by indicating that the changed field is 'shape'. To simplify the logging process, record only that the geometry was changed, not the explicit geometric changes. Creation of a new record need not generate a ChangeLog entry, as the creation event is recorded in the DataSources record initially associated with the data item.

Fields:

ChangeLog_ID	*Primary key. Example values = CHL1, CHL2, CHL3, … Null values not permitted*
OwnerTable	*Full name of table that contains owning element, for example, DescriptionOfMapUnits, or OverlayPolys. Null values not permitted*
OwnerID	*Foreign key to any table in the database. Null values not permitted*
ChangedWhen	*System clock date/time. Date and time of update to the indicated records. Null values not permitted*
ChangedBy	*Login name for account under which the application is running. Generally obtained by operating system request. Null values not permitted*
OldValue	*String tuple of former values of all attributes changed, placeholders for unchanged attributes, with a flag for shape. Null values OK if entry documents a new feature record*
NewValue	*String tuple of new values of all attributes changed, with placeholders for unchanged attributes, flag for shape. "Deleted" is special value. Null values not permitted*
Notes	*Place to (optionally) record why an attribute or shape has been changed. Null values OK*

Suggestions regarding workflow

Attributing ContactsAndFaults

There are at least two possible workflows for attributing the lines in ContactsAndFaults. The most efficient workflow may be a hybrid of these.

(1) Lines may be assigned values of Symbol. Then, perhaps by sorting the ContactsAndFaults attribute table on Symbol and using the Field Calculator in ArcMap, appropriate values of Type, IsConcealed, and LocationConfidenceMeters may be assigned in bulk. The use of standard values for LocationConfidenceMeters should be noted in formal metadata (that is, sections Enumerated_Domain_Value, Enumerated_Domain_Value_Definition, and Enumerated_Domain_Value_Definition_Source) for the feature class. Because queried line symbols may reflect uncertain ExistenceConfidence and (or) uncertain IdentityConfidence, these values will have to be assigned individually for each queried line. Fortunately, queried lines are relatively uncommon.

This work flow requires designating blanket values of LocationConfidenceMeters for "certain", "approximate", and "inferred" lines (though note that such values could subsequently be modified on a per-line or by-area basis).

(2) Lines may be assigned values of Type, IsConcealed, LocationConfidenceMeters, ExistenceConfidence, and IdentityConfidence. This will probably be done with the aide of an extension to the ArcMap interface that manages these clustered attributes. Symbol values may then be calculated with code of the form

if Type = 'contact' **and** LocationConfidenceMeters < ConfidenceZone(mapscale) **and** ExistenceConfidence = 'certain' **and** IdentityConfidence = 'certain' , **then** Symbol = '1.1.1'

"01.01.01' is the string that identifies "Contact—Identity and existence certain, location accurate" in the Geological Survey of Canada's implementation of FGDC-STD-013-2006, the FGDC Digital Cartographic Standard for Geologic Map Symbolization. Alternately,

if Type = 'contact' **and** LocationsConfidenceMeters > ConfidenceZone(mapscale) **and** ExistenceConfidence = 'certain' **and** IdentityConfidence = 'certain' , **then** Symbol = "01.01.03'

'01.01.03' is the string that identifies "Contact—Identity and existence certain, location approximate" in the implementation of the FGDC Standard.

ConfidenceZone(mapscale) is the permissible uncertainty for an accurately located line at a given scale. The confidence zone might be calculated as:

ConfidenceZone(mapscale) = 0.001 meters * ScaleDenominator

In this case, for 1:24,000 scale, ConfidenceZone is 24 meters, and for 1:100,000 scale, it is 100 meters. Note that the ConfidenceZone is specific to the scale of the visualization. If visualization scale changes the calculation must be repeated and the symbolization may change. The multiplier (0.001 meters, above) may vary from map to map and should be specified in the metadata for the dataset as a whole. Alternatively, for regions of markedly different location confidence within a map (for example, lowland areas underlain by sediments, versus mountainous areas underlain by igneous rock) the ConfidenceZone might be separately specified for each area. Again, such practice should be identified in the metadata for the dataset as a whole.

Splitting lines to localize ornament (for example, bar-and-ball on normal fault) is bad practice

Use annotation points, a point in the OrientationPoints feature class, cartographic representations, or some other method that preserves the continuity of the line.

Building MapUnitPolys

Polygons should be built from a selection set or layer definition of those lines from ContactsAndFaults that are not tagged with an IsConcealed value of 'Y', are not fault dangles, and are not fault segments that cut the same unit on both sides of the fault.

DescriptionOfMapUnits table and DMU text

Authors need not manually create both the DescriptionOfMapUnits table and the DMU text. One may create the DMU text in a word processor, annotate a printed copy of the DMU with HierarchyKey, and then copy and paste the text for MapUnit, Name, Age, and Description into DescriptionOfMapUnits. Add the previously-determined values for HierarchyKey. Then add values for the remaining fields.

Alternately, one may create the DescriptionOfMapUnits table first, probably copying text for the Description field from a word-processing document, and then run script ncgmp09_dmu2odt.py to create fully-formatted DMU text in the Open Document file format (ISO/IEC 26300:2006, *http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=43485*, see also *http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=office*). The Open Document format is supported by several word-processing programs, including OpenOffice.org (available at no charge for Linux, Mac, Solaris, and Windows operating systems, see *http://www.openoffice.org*). The *.odt file produced by ncgmp09_dmu2odt.py may be opened with OpenOffice.org and "saved as" to a variety of other formats, including Microsoft Word .doc format. This .doc-format text may be placed into page-layout software used for map layout (for example, Adobe InDesign) with full retention of all formatting.

Script ncgmp09_dmu2odt.py depends on these conventions:

(1) Permissible values for ParagraphStyle are Heading1, Heading2, Heading3, Heading4, Heading5, Headnote (but see point 7, following), DMU1, DMU2, DMU3, DMU4, DMU5, and N/A

(2) Special formatting within the Label, Name, and Description fields is supported with the following HTML-style markup tags:

…	*bold*
<i>…</i>	*italic*
_…	*subscript*
[…]	*superscript*
<ga>…</ga>	*FGDC GeoAge font (font must be present on host computer)*

(3) Multiple formatting tags may be nested, but all must terminate at the same point:

This is bold and <i>this is bold-italic</i>)	*works*
<i>This is bold-italic</i> and this is bold	*doesn't work*
<i>This is bold-italic</i> and this is bold	*works*

(4) Text in the Description field may contain multiple paragraphs. Such paragraphs must be denoted either with the break tag (
) or paragraph tags (<p>…</p>)

(5) Heading text is entered in the Name field

(6) Heading1 is used for "DESCRIPTION OF MAP UNITS". This heading need not be present in table DescriptionOfMapUnits; if absent, it will be supplied automatically. Highest-level headings within the DMU (for example, UNCONSOLIDATED DEPOSITS, BEDROCK) have ParagraphStyle = Heading2

(7) Headnotes may be entered in a separate row of the DMU table, with ParagraphStyle = Headnote and text in the Name or Description field, or entered in the Description field of the heading row. The latter is preferable. If headnote text does not contain initial and final square brackets ([]), brackets will be added

(8) ParagraphStyle = N/A signifies that a row is not to be translated to DMU text, for example, for MapUnit = water, and overlay units, that by convention are not described in Description of Map Units.

Character and paragraph formats applied by ncgmp09_dmu2odt.py are based on a draft style sheet for map layouts that was created by Taryn Lindquist (USGS, Menlo Park). These formats may be altered by editing files ncgmp09_dmu2odt.py (for character styles) and styles.xml (for paragraph styles). The latter is contained within ncgmp09_dmu2odt-template.zip.

Formal metadata

Much of the tedium of creating formal metadata may be automated once names of entities within the database are closely defined (for example, this standard) and internal data dictionaries in the form of tables DescriptionOfMapUnits, Glossary, and DataSources are available. Script ncgmp09_Metadata.py is an effort in this direction. To use the script:

1) Properly fill in the Glossary, DataSources, and DescriptionOfMapUnits tables. Use script ngmp09_Validate.py to check that all cross references are complete.
2) In ArcCatalog, use the metadata editor to create metadata for feature dataset GeologicMaps. You need not supply any Entity and Attribute information. Ensure that the Identification/Supplemental Information field mentions the base map to which geologic information was fit and the nominal map scale of the database.
3) Run the script, which will:
    a) Create metadata records for all elements of the geodatabase, using the identification, spatial reference, distribution, and metadata reference information from the GeologicMap metadata record.
    b) Query the database and, for each table and feature class, create appropriate stubs for each entity and each attribute.
    c) Fill out definition and definition-source fields, using dictionaries derived from this documentation (see script ncgmp09_definition.py)
    d) Recognize most attributes with enumerated-value domains and query the feature class to establish these domains. Define each enumerated value, using the internal data-dictionary tables of the database.
    e) Recognize some unrepresentable domains and some range domains, and write appropriate attribute-domain metadata.
    f) Write a log file that flags all entities, attributes, and values which remain undefined
    g) Append Entity-Attribute information from each feature class to the metadata for the containing feature dataset.
    h) Write an appropriate metadata record for the geodatabase as a whole.
4) In ArcCatalog, import the metadata record for the geodatabase as a whole. You may also have to view each constituent metadata record and click the Update button to set the Spatial Data Organization Information.
5) Fix any omissions that are identified in file <geodatabaseName>_metadata-errors.txt, using the metadata editor in ArcCatalog.

Encoding additional information

Some sets of geologic map data contain additional information that can and should be incorporated into the database. There are multiple options for storing such data.

First, be absolutely certain that such information cannot be mapped into existing feature classes or fields in the database design. Second, consider storing such data in tables ExtendedAttributes and (for age information) GeologicEvents. Third, add new fields to existing tables. Or, fourth, create a new feature class or non-spatial table. The choice between options 2, 3, and 4 should be driven by (a) how many data are there? (if attributes are only known for a few features, ExtendedAttributes is a more likely choice), (b) where are database users most likely to find and understand the data? and (c) what option is the least work and the least likely to result in transcription errors?

Appendix D. Frequently Asked Questions

What about annotation?

There are multiple ways to create and store annotation. We are not sure what data structure will best facilitate publication-quality cartography and allow economical creation and editing of annotation, so we have not prescribed a protocol for annotation. Map authors may wish to create one or more ESRI annotation feature classes along with instruction on how to use them.

My map is a grid. How does it fit into this design?

Grid-based datasets are outside the scope of this design. Suggestions for good raster-based database design are encouraged.

How should I encode structure contours?

You have at least two choices. Structure contours may be encoded in an IsoValueLines feature class, with Type="top Formation X" (or whatever is contoured), with a corresponding Glossary entry for "top of Formation X" that clearly defines the contoured surface. The Glossary entry should also define the units used for the Value field, for example, meters above NAVD88. Alternately, create a new, appropriately named line feature class (for example, StructureContours) with an elevation attribute.

Contours are difficult to analyze automatically. The information contained in structure contours might be better stored as a raster (ESRI grid) or triangulated irregular network (TIN).

How do I represent dikes?

Again, two choices. (1) Dikes are bodies of rock with finite extent. They may be represented as polygons (in feature class MapUnitPolys) of a MapUnit (for example, Volcanic dikes) that is defined in DescriptionOfMapUnits and the polygons are surrounded by contacts (encoded in feature class ContactsAndFaults). This representation works with wide dikes and large map scales. As the scale decreases and the dikes narrow, this representation does not work. (2) Dikes are effectively of infinitesimal width and are represented as lines of Type = 'dike' (or perhaps Type = 'Tertiary andesite dike') that are part of feature class OtherLines. Or maybe they are part of feature class 'DikesAndSills'.

Small areas of distinct rock type (for example, intrusive necks, limestone blocks in a continental-slope olistostrome, blueschist knockers in mélange) present the same choice. Either represent them as polygons in MapUnitPolys, bounded by contacts and (or) faults in ContactsAndFaults, or represent them as points (with, for example, Type = 'intrusive neck' or 'limestone block') in a RockUnitPoints feature class.

Does this standard apply to a visualization of already-published data?

No. However, it does apply to a digital transcription (automation) of a geologic map that has previously been published in analog (paper or PDF) form.

How do I encode a 3-D geologic map?

ArcGIS, along with most other GIS software, was not designed to handle 3-D (volume) data. A useful approximation to a fully 3-D GIS is provided by a stack-unit map (see R.C. Berg and J.P. Kempton, 1988, Illinois State Geological Survey, Circular 542), in which the Earth's surface is divided into polygons that are characterized by the vertical succession of layers beneath each polygon. Many boundaries between polygons are not map-unit boundaries at the surface, but the location of lateral boundaries (pinch-outs, facies changes) below the surface.

To encode a stack-unit map, add field "MapUnitsStack" (type=Text, length ≥ 255 characters) to feature class MapUnitPolys. Values of this field are chains of triplets, in the form $MapUnit_1$:$Qualifier_1$:$ScientificConfidence_1$, $MapUnit_2$:$Qualifier_2$:$ScientificConfidence_2$, …, where each triplet represents a geologic layer, numbered from the surface down, and

MapUnit – has values of MapUnit from DescriptionOfMapUnits
Qualifier – records thickness, continuity, or other attributes. Values of Qualifier are defined in Glossary
ScientificConfidence – records the certainty with which MapUnit and Qualifier are known

$MapUnit_1$ should be identical to the value of MapUnit in MapUnitPolys. $ScientificConfidence_1$ should reflect the value of IdentityConfidence; it many not be identical because of uncertainty in $Qualifier_1$.

The *Notes* field is empty for all records in my ContactsAndFaults feature class. May I delete this field?
Please don't delete required fields. Retaining all required fields, even when empty, makes it easier to write code to analyze and manipulate the database.

What about my fault map? It doesn't show geologic units.
A fault map is not a geologic map, so this standard does not apply. However, most fault maps are analogous to parts of geologic maps and this standard may provide useful guidance. Faults are lines that could be encoded in ContactsAndFaults and associated tables. There could be at least one polygon, outlining the mapped area, and its map-unit might be 'area covered by this map'.

May I give my clients databases in another format?
Certainly. But make these formats available also.

My report has an auxiliary map showing the distribution of sedimentary facies in the Miocene. Where does this map fit in this design?
The answer varies. Not all information depicted via an analog auxiliary map needs a separate digital map (feature class). Distribution of Miocene sedimentary facies could be handled via ExtendedAttributes for polygons of Miocene sedimentary rocks, via overlay polygons (OtherPolys), or via a new polygon feature class. Use your judgment.

How can I tell if a database is compliant?
Try testing the database with script ncgmp09_ValidateDatabase.py. Note that passing the tests in this script does not ensure compliance. However, if a database fails these tests it is not compliant.

How do I use one of these databases to make a publication-quality map image?
This is a non-trivial problem. By standardizing a database design we hope to see the emergence of community tools to solve it. Here are some hints: (A) Proper symbolization of faults with line ornaments (thrust triangles, extensional fault ticks) that are segmented by abutting contacts and (or) are locally concealed requires that you create a continuous fault trace analogous to 'routes' in workstation Arc-Info. Draw individual fault arcs as thick lines, thick dashed lines, and thick dots. Smooth (generalize, spline) the metafaults and draw them with thrust triangles or extensional ticks as appropriate, but no line stroke. (B) Create good annotation (see FAQ on annotation above). We are not aware of tools that successfully automate this task. Dip and plunge values for measured orientations, text associated with other point data, map-unit labels, and place names all may need to be positioned, eliminated, duplicated, or moved and have leaders added (unit labels). (C) Do as much of the preparation of the map image in ArcMap as possible. If necessary, the map image(s) can be exported to Adobe Illustrator, translating fonts as needed, for detailed graphic fine tuning. Insofar as possible, avoid cartographic work in Illustrator or similar software as this often leads to synchronization problems, with the geology portrayed on the map image different from that recorded in the database. (D) Lay out the map sheet with page-layout software (for example, Adobe InDesign), not Illustrator, as text formatting and figure placement are much easier.

I still don't know what metadata for a geologic map should look like. What do I do?
See *http://geology.usgs.gov/tools/metadata/*

Who is going to enforce this?

If adopted by the National Cooperative Geologic Mapping Program, conformance to some degree may be required on delivery of products to the Program. If adopted by the USGS as a whole, Science Publishing Network may check for conformance as part of the publication process. If the design is widely adopted, users will demand conformance so that tools developed to manipulate these databases work.

I've got a better design for a standard geologic-map database. How do I go about getting this proposal changed?

See Review, comment, and revision section, above.

The National Geologic Map Database Project – 2009 Report of Progress

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Introduction

Development and management of science databases for support of societal decisionmaking and scientific research are critical and widely recognized needs. The National Geologic Mapping Act of 1992 (*http://ncgmp.usgs.gov/ncgmpabout/ngmact/ngmact1992*) and its subsequent reauthorizations stipulate creation and maintenance of a National Geologic Map Database (NGMDB, *http://ngmdb.usgs.gov*) as a national archive of spatially referenced geoscience data including geology, paleontology, and geochronology. The Act further stipulates that all new information contributed to the NGMDB should adhere to technical and science standards that are to be developed as needed under the guidance of the NGMDB project. Development of a national database and its attendant standards is a daunting task requiring close collaboration among all geoscience agencies in the U.S., at the State and Federal levels. The Act, therefore, creates the environment within which the USGS and the Association of American State Geologists (AASG) can collaborate to build the NGMDB and also serve the needs of their own agencies.

The congressional mandate for State-Federal collaboration on the NGMDB has proven invaluable, facilitating progress on many technical issues that would otherwise have been much more difficult to achieve by separate efforts within agencies. The NGMDB's long record of accomplishment owes a significant debt to its many collaborators and to the institutions with which it interacts (appendix A). At numerous meetings during the year, technical plans and progress are reported, and discussion and comment is requested; these activities are recorded each year by a progress report in the DMT Proceedings. In order to minimize repetition in this report, we have limited the background and explanatory information, which are contained in previous reports of progress (appendix B; in particular the 2005 report); however, some repetition is considered necessary here in order to provide background for first-time readers.

Strategy and Approach

From the guidance in the National Geologic Mapping Act, and through extensive discussions and forums with the geoscience community and the public, a general strategy for building the NGMDB was defined in 1995 (see Soller and Berg, 1995 and 1997, in appendix B). Based on continued public input, the NGMDB has evolved from that concept to a set of resources that substantially help the Nation's geological surveys provide to the public, in a more efficient manner, standardized digital geoscience information.

The NGMDB is designed to be a suite of related databases, products, and services consisting of (1) a Map Catalog containing information and Web links for all paper and digital geoscience maps and related reports of the Nation, and images of many of these maps, (2) the U.S. Geologic Names Lexicon, (3) the Mapping in Progress Database, (4) nationwide geologic map coverage at intermediate and small scales, (5) an online database of geologic maps (predominantly in vector format; planned as a distributed system), (6) a set of Web interfaces to permit access to these products, and (7) a set of standards and guidelines to promote more efficient use and management of spatial geoscience information. The NGMDB system is a hybrid – some aspects are centralized and some are distributed, with the map information held by various cooperators (for example, the State geological surveys). Through a primary entry point on the Web, users can browse and query the NGMDB, and obtain access to the information wherever it resides.

The project's success depends on strong endorsement by agency management, and collaboration with technical consultants, in the USGS and AASG. This support is critical because (1) the project has responsibility for standards development, and standards cannot successfully be implemented until they are widely endorsed, (2) many of the various project tasks are at least partly conducted by collaborators rather than by funded project members, and (3) this project is national in scope and does not fit cleanly into the USGS regional organizational structure. The project therefore relies on USGS and AASG management to implement and maintain certain policies and standards that support NGMDB objectives and to help promote constructive interaction with new initiatives whose objectives may be similar (for example, the USGS National Geological and Geophysical Data Preservation Program; the NSF-funded U.S. Geoinformatics Network project).

Example "Outcomes"

In yearly proposals for project funding, the USGS requires that three examples of a project's impact and contributions be provided; the NGMDB project's are as follows.

1. On a monthly basis, the NGMDB Web site receives 50-60,000 visits from about 25,000 users (nearly all non-USGS). This high level of Web traffic spawns numerous user requests for information and assistance, as these users vary widely in interest and background, and include schoolchildren, homeowners, local government planners, and professional geologists. Mostly they use the NGMDB data-discovery databases (Map Catalog, Geolex, Mapping in Progress) to find geoscience maps and publications. With many of these users we have personal contact by email to ensure they find what they need.
2. A surficial geologic map database of the conterminous U.S. was prepared and published by the NGMDB project in 2009 (Soller and others, 2009). It has been incorporated as an essential part of the new national Terrestrial Ecosystems classification system (now published as USGS Professional Paper 1768, supported by a set of Scientific Investigations Maps). This surficial geologic map also is being used for regional-scale research and mapping of plant distribution, the effects of geologic conditions on animal habitats and distribution, air-mass trajectories (for example, where do the winds blow the salty materials from dry lake beds), and earthquake shear wave velocities in the United States.
3. For 13 years, the NGMDB project has organized annual workshops on "Digital Mapping Techniques." The workshops support the needs of State and Federal agencies, for information exchange and for development of more efficient methods for digital mapping, cartography, GIS analysis, and information management. These workshops have been very successful and have significantly helped the geoscience community converge on more standardized approaches for digital mapping and GIS analysis. The workshop Proceedings are widely read and consulted for technological advances and trends. As a response to information shared at these workshops, agencies have adopted new, more efficient techniques for digital map preparation, analysis, and production. Examples are numerous; here is one from the first DMT meeting: "After attending the Digital Mapping Techniques '97 (DMT '97) conference in Lawrence, KS, we decided to model our digital cartographic production program after that of the Nevada Bureau of Mines and Geology ...[which] expedited our overall cartographic production. Months of trial-and-error digitizing and interaction between geologists and technicians were replaced by a single scanned image that could be quickly drafted. In about two weeks, the 1:24,000 Alameda geologic quadrangle went from an inked mylar to a multicolor plotted map sheet, complete with cross sections."

Project Organization

The project consists of a set of related tasks that will develop, over time, a NGMDB with increasing complexity and utility. This is being accomplished through a network of geoscientists, computer scientists, librarians, and others committed to supporting the project's objectives. ***Phase One*** of this project principally involves the building of a comprehensive Geoscience Map Catalog of bibliographic records and online images of all available paper and digital maps, and books, guidebooks, and journal articles that either include maps or describe the geology of an area; although the project's name refers only to maps, the Catalog contains information related to the numerous earth-science themes specified in the National Geologic Mapping Act of 1992. Critical to this first phase is the design and development of the U.S. Geologic Names Lexicon (Geolex), the Mapping in Progress Database, and a database and archive of USGS Paleontology and Stratigraphy reports. ***Phase Two*** addresses the development of standards and guidelines for geologic map and database content and format. ***Phase Three*** is a long-term effort to develop a distributed database containing nationwide geologic map coverage at multiple map scales, populated according to a set of content and format specifications that are standardized through general agreement among all partners in the NGMDB (principally the AASG and USGS); this database would be integrated with the databases developed in Phase One. The NGMDB project's technology and standards development efforts also are coordinated with various entities, including the Federal Geographic Data Committee, ESRI, the North American Geologic Map Data Model Steering Committee, the NSF-funded U.S. Geoinformatics Network project, the IUGS Commission on the Management and Application of Geoscience Information (IUGS CGI), the IUGS Commission on Stratigraphy, the OneGeology initiative, and the IUGS-affiliated Commission for the Geological Map of the World.

A full realization of the project's third phase is not assured and will require a strong commitment among the cooperators as well as adequate technology, map data, and funding. The project will continue to assess various options for development of this database, based on realistic funding projections and other factors. During the development of these phases of the NGMDB, extensive work will be conducted to build Web interfaces and search engines and to continually improve them, and to develop the data management and administrative protocols necessary to ensure that the NGMDB will function efficiently in the future. The NGMDB's databases and project information are found at *http://ngmdb.usgs.gov*.

Progress in 2009

Phase One

A wealth of geoscience information is available in various paper and digital formats. With the emergence of the Web, the public has come to expect rapid, easy, and unfettered access to government data holdings. Geoscience data must therefore become widely available via the Web, and the concepts presented in its products must be understandable to the public. If our information is more readily available to the public, and if tools are offered to help integrate and provide access to that information, its utility may be greatly increased.

However, providing effective public Web access to our products presents a real challenge for each geoscience agency, because of new and rapidly evolving technology, restricted funding, new requirements from the user community, and the somewhat confusing array of Web sites at which various types and quality of information can be found. To help address these challenges, Phase One focuses on providing simple, straightforward access to a broad spectrum of geoscience information, and forms the stable platform upon which the other NGMDB tasks and capabilities are based.

Specific accomplishments in 2009 include:

1. Expanded the Map Catalog by ~2,800 records, to a total of ~82,800 records. It now includes 38,700 USGS publications, 30,400 State survey publications, and 13,700 products by other publishers.
2. Engaged all States in the process of entering Map Catalog records. Processed ~2,200 new records for State geological survey publications.
3. In response to NCGMP and AASG requests, and in part to address NCGMP performance metrics required by the Office of Management and Budget, provided (a) index maps showing areas in the United States that have been geologically mapped at various scales and time periods and (b) computations including the number of square miles geologically mapped at intermediate and more detailed scales (see Soller, 2005).
4. In cooperation with USGS Publications Warehouse (PW), continued to process and serve via Map Catalog the many thousand map images scanned by the PW. Collaboration with PW was undertaken to minimize duplication of effort and to better integrate the two systems. From various university libraries (especially from The Ohio State University), acquired hundreds of old publications not yet obtained by PW for scanning; these include rare atlas sheets from USGS Monographs, informally released USGS Strategic Minerals Maps and Reports, and Bulletins from the late 1800s. Publications were cataloged and stored in our offices, to be shipped to a PW contractor for scanning.
5. Continued to add to bibliographic records in the Map Catalog the Web links to online digital maps and reports, mostly to USGS reports served by the PW. About 45 percent of publications listed in the Map Catalog now have at least one such link. Many of these publications have multiple links, to individual map sheets. Worked with PW to begin inserting into their citations the links to images managed by the NGMDB.
6. Continued to process 5,000 files of USGS publications scanned by Alaska DGGS. When completed, files will be loaded to the NGMDB or PW, and citation errors will be corrected in NGMDB, PW, and Alaska databases.
7. Scanned, processed, and loaded into the Map Catalog about 2,000 map images for 1,400 publications.
8. Upgraded and maintained a 12-TB computer for storage of map images and for image processing.
9. Continued to process selected EDMAP deliverables, for inclusion in the Map Catalog.
10. Continued to revise existing records in Geolex. Given the many and disparate origins of this lexicon, revision of existing electronic records inherited from the last-published USGS listing of names (in USGS DDS-6) remains the focus of work. As time permits, critically important stratigraphic information (for example, type localities) is retrieved from the authoritative published USGS lexicons (for example, Bull. 896) and integrated into Geolex.
11. As the first step in the NGMDB database and Web site redesign, Map Catalog and Geolex citations

are being merged into one database to better serve both databases and to provide integrated search and reporting of publications, geologic names, and study area footprints. Included in this time-consuming work is error-checking against the Publications Warehouse citation; any errors found there are reported to their database manager. This work is nearly complete, and the merged database is being prepared to serve the redesign's next step -- enhanced database search and reporting capabilities.

12. Continued to revise the Web statistics that identify the extent to which State geological survey publications are accessed via the Map Catalog. These statistics are now provided to each State geologist, via a password-protected site.
13. Customer service: completed several hundred productive interchanges with Map Catalog and Geolex users, via the NGMDB feedback form and other mechanisms.

Phase Two

Geoscience information increasingly is available in digital format. Within an agency, program, or a project, there are standard practices for the preparation and distribution of this information. However, widely accepted standards and (or) guidelines for the format, content, and symbolization of this information do not yet exist. Such standards are critical to the broader acceptance, comprehension, and use of geoscience information by the nonprofessional and professional alike. Under the mandate of the National Geologic Mapping Act, the NGMDB project serves as one mechanism for coordinating and developing the standards and guidelines that are deemed necessary by the U.S. and international geoscience community.

The NGMDB project leads or assists in development of standards and guidelines for digital database and map preparation, publication, and management. This activity is a challenging one that entails a lengthy period of conceptual design, documentation, and test-implementation. For example: (1) a conceptual data model must be shown to be implementable in a commonly available GIS such as ESRI's ArcGIS; (2) a data-interchange standard must be demonstrated to be an effective mechanism for integrating (for example, through the NGMDB portal) the many and varied data systems maintained by the State geological surveys, USGS, and others; and (3) a map symbolization standard must be implemented in, for example, PostScript or ArcGIS before it can be used to create a map product. Then, of course, each proposed standard must become widely adopted; otherwise, it isn't really a standard. Internationally, the NGMDB participates in venues that help to develop and refine the U.S. standards. These venues also bring our work to the international community, thereby promoting greater standardization with other countries.

The accomplishments listed below address a fundamental NGMDB goal -- to propose a "core" set of standards and guidelines for endorsement by the Nation's geological surveys. Throughout the past decade and more, geological surveys have collaborated on geologic map database design, science terminology, and data interchange standards. Progress has been significant, and was in part facilitated by long-term technical and funding support by the NGMDB project and by the 13 annual DMT meetings.

Specific accomplishments in 2009 include:

1. Organized and led the thirteenth annual "Digital Mapping Techniques" workshop. Developed the agenda, solicited presentations, and worked to prepare the workshop proceedings. Edited the workshop Proceedings from the previous year's meeting (DMT '08, Moscow, ID).
2. Collaborated with the USGS Pacific Northwest project to define a database format for publication of geologic maps. Extensive technical sessions among project geologists served to reconcile minor differences in database design and workflow. The resulting design ("NCGMP09"; see related paper in these Proceedings) is a carefully planned balance between the map-preparation and publication-workflow needs of a mapping project and the long-term, national need to archive standardized geologic map data from many projects. NCGMP09 is an ArcGeodatabase design supported by example map databases, standard vocabularies, documentation, and prototype tools such as error-checking scripts. At DMT'09 it was released for public comment and testing. Design revisions and tool development to facilitate data entry and management are planned.
3. Continued to collaborate with ESRI on an ArcGIS Geology Data Model compatible with NCGMP09.
4. Coordinated work on the FGDC geologic map symbolization standard. Prepared and published online the PostScript version (USGS T&M 11-A2) and the printed version of the standard; for the latter, served as sole means of distribution to all requestors. Responded to numerous inquiries and comments from users.
5. Continued to work with ESRI on implementation of the FGDC standard. Provided technical guidance on science and technical aspects, and on workflows and Arc template design for creating well-symbolized products from legacy maps and new map databases. ESRI publicly released their first version of the implementation at the DMT'09 meeting, and it was well received.
6. Project members served as committee Secretary and as member of the U.S. Geologic Names Committee.
7. Project member served as Chair of FGDC Geologic Data Subcommittee, and managed the

Subcommittee's Web site.

8. Project member served as (a) U.S. Council Member to IUGS Commission for the Management and Application of Geoscience Information (CGI), (b) U.S. representative to DIMAS, the standards body for the Commission for the Geological Map of the World, and (c) USGS technical representative to the OneGeology project.
9. Project member participated in CGI's International Data Model Collaboration Working Group. Contributed to development of the XML-format GeoSciML schema, which is becoming an international data-exchange standard for geoscience information. Served as chair of Concept Definitions Working Group, and continued to advance development of international standard science terminologies.

Phase Three

From the NGMDB project's origin in 1995 it has been the generally held vision, by users and colleagues alike, that the National Geologic Map Database would, principally, be a repository of GIS data for geologic maps and related information, managed in a complex system distributed among the USGS and State geological surveys. The system would offer public access to attributed vector and raster geoscience data, and allow users to perform queries online, create derivative maps, and download source and derived map data. Further, all information in the database would retain metadata that clearly indicates its source (that is, who created a particular contact, fault, or delineation of a map unit contained in the database, and how the feature or attributes were later modified by further study).

To realize this vision would require (1) full commitment and close collaboration among the partners, (2) a flexible and evolving set of standards, guidelines, and data management protocols, (3) a clear understanding of the technical challenges to building such a system, and (4) an adequate source of funding. This task is designed to foster an environment where the distributed database system can be prototyped while these requirements are being considered by the partners.

This is a long-term effort whose fully realized form is, at this time, difficult to predict. It is a complex task that depends on data availability, technological evolution, skilled personnel (in high demand and, therefore, in short supply), and the ability for all participants to reach consensus on the approach. Bearing this in mind, the scope and details of Phase Three have been systematically explored and developed through prototypes. Each prototype addressed aspects of the database design, implementation in GIS software (for example, ArcGIS), standard science terminologies, and software tools designed to facilitate data entry. Each prototype was presented to the participants and the public for comment and guidance. The focus of new prototypes is guided by the comments received.

For example, in FY01 the NGMDB completed a major prototype in cooperation with the Kentucky Geological Survey, the Geological Survey of Canada, the University of California at Santa Barbara, and the private sector (Soller and others, 2002). The principal goal was to implement the North American Data Model (NADM; *http://nadm-geo.org/*) draft standard logical data model in a physical system, and to demonstrate certain very basic, essential characteristics of the envisioned system. That prototype was demonstrated and discussed at numerous scientific meetings, and its data model contributed to development of the North American conceptual data model. The project then considered plans to improve that system by adding more complex geologic data and software functionality. However, it would have required significant new funding at a time when technology and geoscience community ideas on database design were rapidly evolving. Therefore, a more limited approach was pursued in the most recent prototype, in which draft NGMDB science terminologies, a NADM-based database design, and data-entry tools were devised in order for the project to develop a Data Portal that offers public access to a simplified view of GIS data held by various cooperating agencies.

The NGMDB Data Portal was, in late 2008, released for comment to the four participating State geological surveys (Washington, Oregon, Idaho, and Arizona). A revised version was publicly released in June 2009 (*http://maps.ngmdb.us/dataviewer/*). As with previous Phase Three prototypes, further development of this Portal through more collaboration with these States, or others, depends on public response.

Specific accomplishments on this task in 2009 include:

1. Development of standard science terminology. The terminology lists created by NGMDB, IUGS-CGI GeoSciML working group, and others describe aspects of geologic units and materials (for example, their lithology, age, genesis), but not overall nature of the geologic units themselves. Therefore a new terminology was developed to more clearly show, within the constraints of a Web interface, the type of units that are mapped by geologists (for example, "alluvium" rather than "poorly sorted clastic sediment"). This terminology promotes quicker comprehension by integrating the geology across all source maps and by providing simple terms and definitions. Prototyped in FY08, this terminology was revised, documented in a DMT'08 paper (Soller, 2009), and applied to maps used in the Data Portal.
2. This map-unit-based terminology is displayed in the Portal via a Dynamic Legend; as the user zooms and pans across the maps, the Legend automatically updates to show only those map units within the field of view. This feature addresses a common and critical problem with Web-mapping systems

-- effective presentation of complex spatial and textual information within the strict limitations of a Web browser. The software coding, and selection of informative map unit colors and patterns, was a significant challenge.

3. Using the NGMDB Data-Entry Tool (developed in 2007-08), map datasets were revised and retagged as needed, with updated science terminologies. These updates occurred because terminology lists continue to evolve via discussion within the GeoSciML Concept Definitions Working Group and NGMDB.
4. All aspects of the Data Portal’s back-end database and interface design were completed in 2009. These include (i) the Dynamic Legend, (ii) tear-off information tabs or boxes, (iii) converting the back-end database from flat-file (ESRI Shapefile) to a relational database design (in PostGIS) that will be compatible with NCGMP09, and (iv) establishing all links to State geological survey Web-mapping sites and the NGMDB’s Map Catalog and Geolex databases.

Acknowledgments

We thank the USGS National Cooperative Geologic Mapping Program (NCGMP) and the AASG Geologic Mapping Committee for their long-term support for the NGMDB project. We also thank the NGMDB project staff and collaborators for their enthusiastic participation and expertise, without whom the project would not be possible. In particular, we thank: Dennis McMacken, Michael Gishey, and Alex Acosta (USGS-Arizona; Web site and database management); Chuck Mayfield (USGS, Menlo Park; Map Catalog content); Robert Wardwell and Justine Takacs (USGS, Vancouver, WA, and Reston, VA; Map Catalog’s Image Library); Sarah Jancuska (USGS, Reston; biostratigraphic database); Steve Richard (Arizona Geological Survey / USGS, Tucson, AZ; Phase 3 – data model and science terminology); David Percy and Morgan Harvey (Portland State University; Phase 3 – Data Portal). We also thank the many committee members who provided technical guidance and standards (appendix A).

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Appendix A. Principal Committees and People Collaborating with the National Geologic Map Database Project

Geologic Data Subcommittee of the Federal Geographic Data Committee:
Dave Soller (U.S. Geological Survey and Subcommittee Chair)
Jerry Bernard (USDA-Natural Resources Conservation Service)
Courtney Cloyd (U.S. Forest Service, Minerals and Geology Management)
Mark Crowell (Department of Homeland Security, Federal Emergency Management Agency)
Laurel T. Gorman (U.S. Army Engineer Research and Development Center)
John L. LaBrecque (National Aeronautics and Space Administration)
Lindsay McClelland (National Park Service)
Jay Parrish (State Geologist, Pennsylvania Geological Survey)
George F. Sharman (NOAA National Geophysical Data Center)
Dave Zinzer (Minerals Management Service)

Map Symbol Standards Committee:
Dave Soller (U.S. Geological Survey and Committee Coordinator)
Tom Berg (State Geologist, Ohio Geological Survey)
Bob Hatcher (University of Tennessee, Knoxville)
Mark Jirsa (Minnesota Geological Survey)
Taryn Lindquist (U.S. Geological Survey)
Jon Matti (U.S. Geological Survey)
Jay Parrish (State Geologist, Pennsylvania Geological Survey)
Jack Reed (U.S. Geological Survey)
Steve Reynolds (Arizona State University)
Byron Stone (U.S. Geological Survey)

AASG/USGS Data Capture Working Group:
Dave Soller (U.S. Geological Survey and Working Group Chair)
Sheena Beaverson (Illinois State Geological Survey)
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These people help the NGMDB with the Geoscience Map Catalog and GEOLEX. Please see *http://ngmdb.usgs.gov/info/statecontacts.html* for this list.

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Appendix B. List of Progress Reports on the National Geologic Map Database, and Proceedings of the Digital Mapping Techniques Workshops

Soller, D.R., ed., 2009, Digital Mapping Techniques '08—Workshop Proceedings: U.S. Geological Survey Open-File Report 2009-1298, 216 p., *http://pubs.usgs.gov/of/2009/1298/*.

Soller, D.R., ed., 2008, Digital Mapping Techniques '07—Workshop Proceedings: U.S. Geological Survey Open-File Report 2008-1385, 140 p., *http://pubs.usgs.gov/of/2008/1385/*.

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Geologic Mapping at the Missouri Division of Geology and Land Survey

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Background

The Missouri Division of Geology and Land Survey (DGLS) produces maps that show the distribution of surficial material and bedrock units. The maps are produced for distribution at a scale of 1:24,000. Regional maps are published at smaller scales, such as 1:100,000, and are compiled from the larger scale geologic maps. The maps are provided to the public as paper copies or as digital image files.

Geologists at DGLS began using GIS to produce geologic maps in 1997 by using ArcView™ to recreate maps previously drawn on paper. Since that time, they have transitioned to ArcGIS™ and use GIS to compile the geologic maps. The geology of approximately 110 7.5-minute quadrangle areas has been produced digitally since 1997. The mapmaking and production process has evolved since that time. DGLS is currently in the process of transitioning from paper to electronic field notes.

Most information used to make a new geologic map comes from field work. Geologists collect information about exposures of bedrock and surficial materials and record the locations where the data were collected. To create a bedrock geologic map at a scale of 1:24,000, geologists try to collect at least 11 control points per square mile, or about 660 control points per 7.5-minute quadrangle. A control point consists of the location of a bedrock exposure along with a description that includes formation name, lithology and structural information such as strike and dip measurements. Control points are collected along roadways and on foot traverses. A geologist will walk from 50 to 100 miles during a field season to prepare a geologic map for one 7.5-minute quadrangle. Most field work takes place during the fall, winter, and early spring when leaves are down. U.S. Geological Survey (USGS) 1:24,000-scale topographic maps have traditionally been used for data collection and as the base map for the hard copy version of the geologic map. DRG images of these maps currently serve as bases for the geologic maps.

Data Collection

Databases of well logs and measured sections are maintained at the DLGS. For each area to be mapped, this information is added to an ArcMap project prior to the beginning of the field season. Information also is included from published references relating to the study area. Aerial imagery, stored on the department's data server, may reveal lineaments related to geologic structures, and so this information also is incorporated into the GIS project. Standards for data file names and database field names are defined in "Missouri Technical Geological Mapping Standards", an internal, working document (Middendorf, 2008). A personal geodatabase is developed for outcrop descriptions, spring locations and any other data that may be collected in the field. Ultimately, the goal is to create a centralized database for field data collection. The "Get data for ArcPad" tool is used to check out data for field editing. Panasonic Toughbook™ notebook computers allow the geologists to carry this information to the field.

Field data are collected on the Toughbook notebook computers loaded with DRGs and ArcPad™. A Garmin™ GPS receiver communicates with the Toughbook via Bluetooth technology. The small GPS receiver is easily held in the hand as the computer is cradled in the crook of an arm just as any notebook would be held. Ease of carrying is important since long hikes are required to collect required information for the geologic map. This equipment allows the geologist to enter field data directly into a GIS while doing a traverse or to collect field data using pen and paper and then to transfer the data in the motel room in the evening. Field data are collected into shapefiles in the ArcPad project.

The outcrop database is simple and flexible. It contains four fields – field ID, formation, lithology, and structures. Only the formation field has a specified domain. This domain contains all of the unit names that are expected to be present in the study area. The lithology and structures fields are text fields where the geologist can describe those attributes in 40 characters or less. Supplemental information is collected on paper. At the end of the project, paper field notes are typed into Word™ or scanned. These notes are archived with the ArcMap project on the server.

When the geologist returns to the office, the field data are incorporated into the ArcMap project by using the "Check in edits from ArcPad" tool. Final interpretation of the field and existing file data is done in the office. This is when geologic contacts and structural features, such as faults and folds, are added to the project.

Map Development

Summary and interpretation of the data is represented with a map showing the distribution of map units and locations of geologic structures. It also includes text descriptions and cross sectional representations. The line, point, and polygon shapefiles that respectively represent geologic structures, strike and dip measurements, and distribution of map units are drawn in ArcMap by the geologist who collected the data. Points locating observed contacts are also included on the maps. These shapefiles are archived for smaller scale compilations.

Map layout includes components such as text description of units, north arrow, cross sections, a correlation chart, and a stratigraphic column. The bedrock geologic map, cross sections, stratigraphic column, correlation chart, and a map showing data point locations are developed as data frames in ArcMap. Description of units, structural features, a discussion of economic geology, and references are included as text boxes. The legend is a combination of graphics and text boxes.

In 2008, DGLS began using the CrossViewTM plug-in for ArcMap to construct the geologic cross sections included in the layout (CrossView is available from A-Prime Software, *http://www.aprimesoftware.com/*). CrossView significantly reduces the amount of time necessary to create a cross section. With this plug-in, the geologist can display information from well logs and even drape the newly created geologic map across the topographic profile.

Standard USGS DRGs, scanned at 250 dpi, have been used by DLGS as digital base maps for geologic maps for several years. However, the resulting geologic maps were sometimes difficult to read. It was determined that the appearance of the final geologic maps could be improved by starting with better quality base maps. Base map appearance has been improved in two ways. The appearance has been muted by representing contour lines and text as a dark gray color, allowing the geology to be more prominently displayed. In addition, DGLS has begun using DRGs produced in-house at higher resolution than the standard USGS DRGs. To accomplish this, a paper topographic map is scanned at 400 dots per inch. Adobe Photoshop CS3TM is used to convert the TIF file to a 32 index color TIF image and to remove the green (forest) color from the image, as well as to remove some of the map collar. The higher resolution base maps will improve the legibility of the paper product and the appearance of the digital image (Starbuck and Loveland, 2009). Map layouts are exported from ArcMap as PDF files for on-demand plotting. Data and maps are archived as shapefiles. A summary of geologic mapping procedures at DLGS is shown in figure 1.

Looking to the Future

The geologic mapping process at DGLS continues to evolve. Server limitations will require an archival method that makes full use of geodatabases as well as shorter file and folder names. DGLS is currently looking at methods of creating vector-based base maps in order to obtain a crisper-looking map. Certainly, as the use of field computers becomes routine, mappers will see new ways to use them.

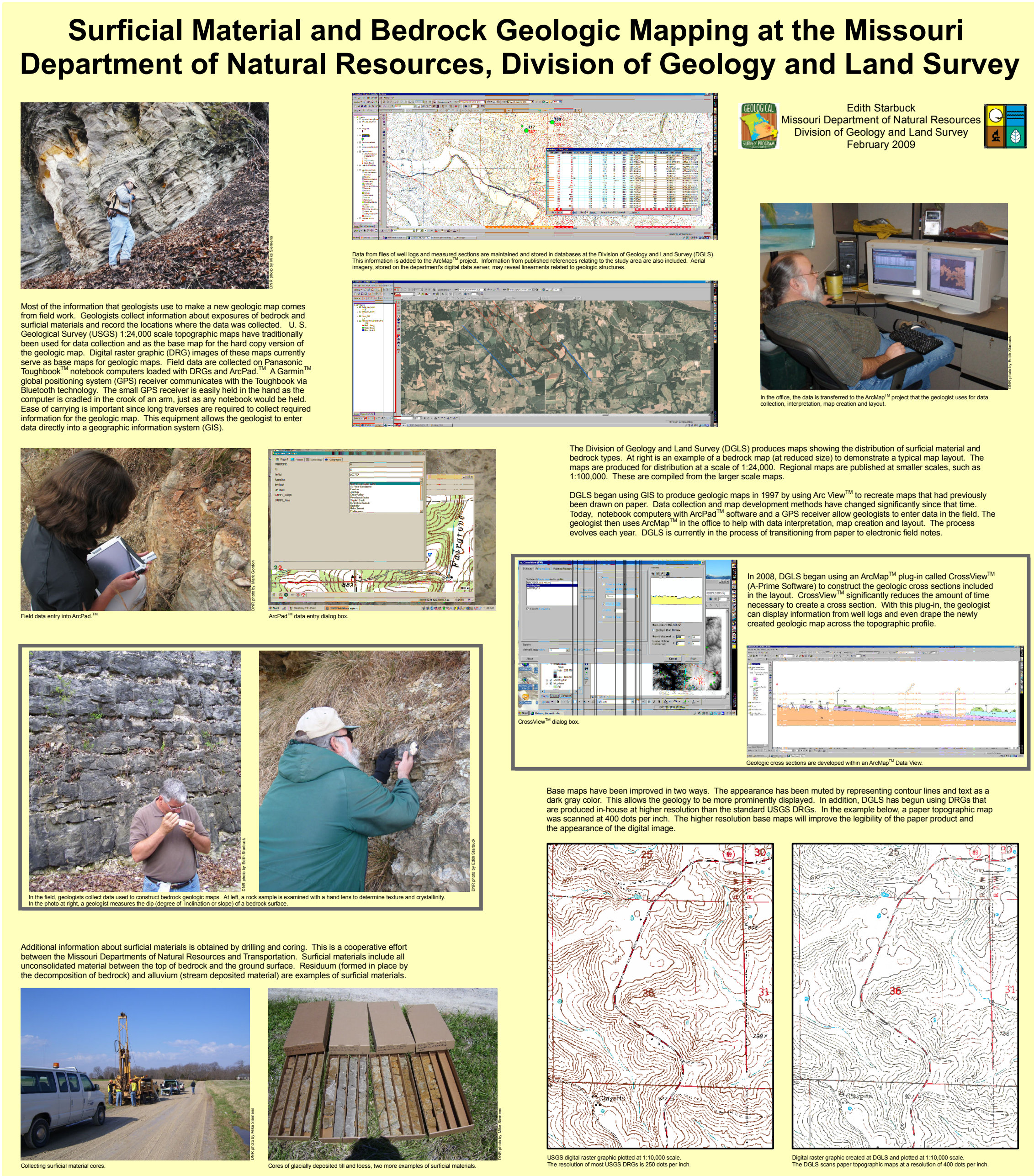

Figure 1. Surficial material and bedrock geologic mapping at the Missouri Division of Geology and Land Survey (a full-resolution copy of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Starbuck.pdf*).

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Database Design for Map of Surficial Materials in the Conterminous United States

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The Earth's bedrock is overlain in many places by a loosely compacted and mostly unconsolidated blanket of sediments, or by weathered, residual soil material. For the conterminous United States, these materials were shown on a map by Soller and Reheis (2004). That map was published as a PDF file, from an Adobe Illustrator-formatted version of the provisional unpublished GIS database. The provisional GIS files were further edited and processed without significantly modifying the content of the published map and were published in Soller and others (2009). This paper describes the design of the published database (fig. 1).

The Transition from Compiled Map to Database

The map is a generalized (1:5,000,000-scale) depiction of the sediments and the weathered rock material at land surface, and the approximate thickness of the entire succession of sediments that overlie bedrock. The geologic materials are classified into 14 genetically based groups that are subdivided into 55 map units by factors such as texture, source material, and sediment thickness (see Soller and Reheis, 2004). The length of the Description of Map Units is typical to relatively verbose and includes descriptive text in subheadings. Because this is a regional map, the text is relatively generic as compared to more detailed maps (fig. 2).

The map was compiled from two GIS files: (1) for the conterminous U.S. east of 102 degrees west longitude, a 1:2,500,000-scale compilation served as the principal source, and (2) to the west, GIS files of state-scale and more detailed maps were compiled together. The eastern and western GIS map files then were combined into a single PostScript file and, using Adobe Illustrator, the map was prepared and published in PDF format without an accompanying GIS database. The decision to not simultaneously publish the database was not made lightly, but was necessitated by budget and time constraints.

While preparing the map in Adobe Illustrator, certain map units were revised in order to address peer review comments that were received after the export from ArcInfo. To prepare the GIS database for publication, these edits needed to be incorporated. The two ArcInfo files (east and west parts of the map) were written to Export format, and ESRI shapefiles were generated in ArcMap. Harumi Warner (USGS, Denver) incorporated the edits and submitted to the senior author the two shapefiles (east and west parts of the map) for verification.

East and west polygon shapefiles then were merged and converted to a file geodatabase. Geodatabase topology was created and topological error logs were generated. Logs listed numerous areas where problems in topological relationships existed. Common topological problems included polygons that overlapped or had gaps between them, overlying line layers (contacts, faults, and so on) that were not coincident with polygon boundaries, and line features that self overlapped. Topology rules were set in ArcMap to remove errors and create a topologically clean layer. For attribution purposes, subtypes were assigned to the geologic contacts layer. The use of subtypes ensured data consistency during the editing stages of the project. Feature class symbolization was created to closely resemble the printed version of surficial materials map and was exported to ESRI layer files.

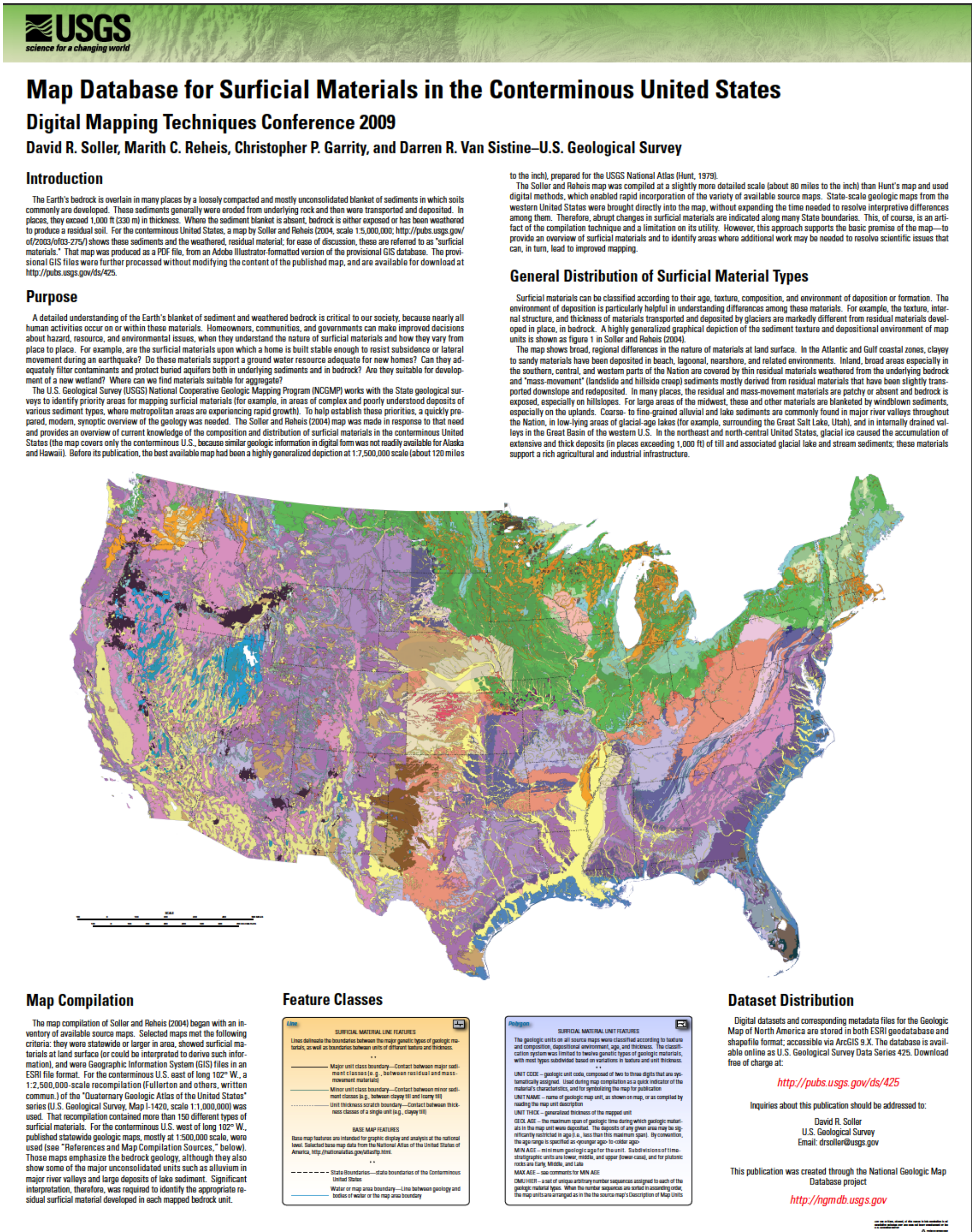
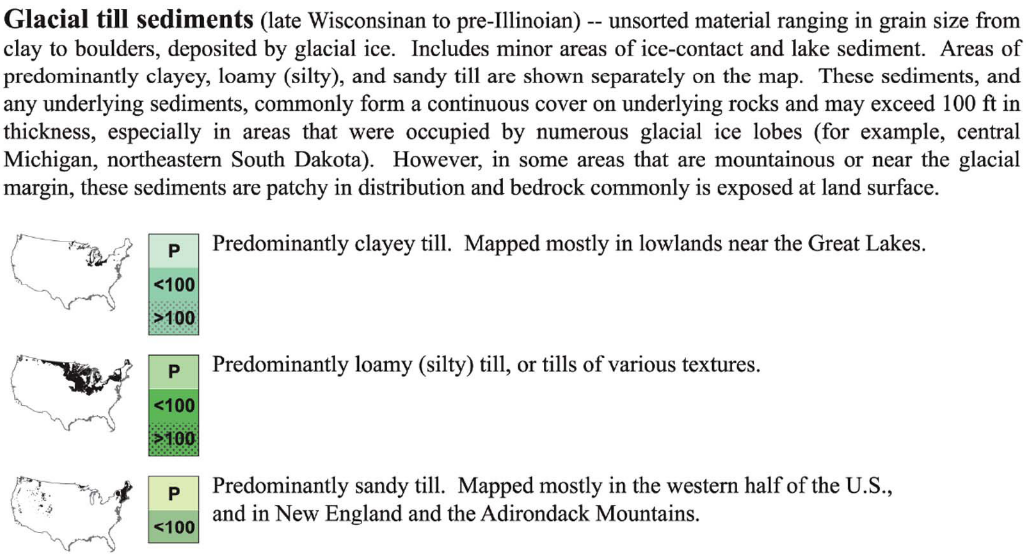


Figure 1. DMT'09 poster "Database design for map of surficial materials in the conterminous United States" (a full-resolution copy is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Soller2.pdf*).



Glacial till sediments (late Wisconsinan to pre-Illinoian) -- unsorted material ranging in grain size from clay to boulders, deposited by glacial ice. Includes minor areas of ice-contact and lake sediment. Areas of predominantly clayey, loamy (silty), and sandy till are shown separately on the map. These sediments, and any underlying sediments, commonly form a continuous cover on underlying rocks and may exceed 100 ft in thickness, especially in areas that were occupied by numerous glacial ice lobes (for example, central Michigan, northeastern South Dakota). However, in some areas that are mountainous or near the glacial margin, these sediments are patchy in distribution and bedrock commonly is exposed at land surface.

Predominantly clayey till. Mapped mostly in lowlands near the Great Lakes.

Predominantly loamy (silty) till, or tills of various textures.

Predominantly sandy till. Mapped mostly in the western half of the U.S., and in New England and the Adirondack Mountains.

Figure 2. Excerpt from the Description of Map Units.

Objectives

The map was compiled with the intention of providing information about the surficial geologic framework that could be applied, mostly by nongeologists, to a wide spectrum of issues. For example, the database was incorporated as an essential part of the new national Terrestrial Ecosystems classification system (Sayre and others, 2009; Cress and others, 2010). Provisional copies also have been used for regional-scale research and mapping of plant distribution, the effects of geologic conditions on animal habitats and distribution, air-mass trajectories (for example, where do the winds blow the salty materials from dry lakebeds), and earthquake shear wave velocities in the United States.

It was therefore deemed imperative that the database include descriptive content sufficient to inform the nongeologist. Most GIS files do not directly provide rich description content or attributes but instead rely on the user to consult other documents (for example, text, spreadsheets) in order to find this information. Numerous projects have attempted to remedy this situation by specifying database designs more comprehensive that what is commonly published (for example, see the NCGMP09 design, in this volume). At the time this map was being prepared for publication, the NCGMP09 design was under development, so the database described below adapted to this somewhat unusual map some concepts from preliminary versions of that design. Although it may not be transferable for use with other maps, the reader might gain some insight from our attempt.

Database Design

Rich information content is most efficiently stored in related tables, and so the ESRI Geodatabase format is far more appropriate than the (essentially flat-file) Shapefile format. However, because many users rely on various software's ability to import Shapefiles, we felt it important to release this database in both formats.

Regarding the Geodatabase design, geologic unit polygons and lines each are stored in one feature class ("Surficial Materials" and "Contacts"). The Contacts feature class included one attribute, LINE_CODE; it uses numeric subtype codes for the various map unit boundary types, and displays the text description. In the Shapefile version, an additional field ("CONTACT") was added in order to provide a text description for each LINE_CODE. From the Description of Map Units, information was parsed into these fields in both the Surficial Materials feature class and Shapefile (see the product metadata for details):

- UNIT_CODE – Geologic unit code, composed of two to three digits that are systematically assigned. Used during map compilation as a quick indicator of the material's characteristics, and for symbolizing the map for publication.
- UNIT_NAME – Name of geologic map unit, as shown on map, or as compiled by reading the map unit description (and parent map unit description, if any).

- UNIT_THICK – Generalized thickness of the mapped unit.
- GEOL_AGE – The maximum span of geologic time during which geologic materials in the map unit were deposited. The deposits of any given area may be significantly restricted in age (that is, less than this maximum span). By convention, the age range is specified as <younger age> to <older age>.
- MIN_AGE – Minimum (youngest) geologic age during which materials in the map unit were deposited. This is the minimum age for all sediments in the map unit; the deposits at a specific location may be significantly older.
- MAX_AGE – Maximum (oldest) geologic age during which materials in the map unit were deposited. This is the maximum age for all sediments in the map unit; the deposits at a specific location may be significantly younger.
- DMU_HIER – A set of unique arbitrary number sequences assigned to each of the geologic material types (Table 1). The number sequence is essentially an outline format. When the number sequences are sorted in ascending order, the map units are arranged as in the hierarchical, ordered format shown on the source map's Description of Map Units.

Remarks

Our intention was to provide a map database containing information useful to the general public and the geologist alike. However, the descriptive text for each map unit can be lengthy, and it is common practice to not include this in a Shapefile because of the redundancy. Regarding whether to include text descriptions in a separate table that can be linked to the polygon feature class, there are differing opinions because a table Relate must be established and maintained. In version 1.0 of this database, a table or spreadsheet of the text descriptions was not included, whether by design or accident. It now has been added – either underscoring the evolutionary nature of database design, or the old adage "There's many a slip twixt cup and lip."

Table 1. Geologic unit names and an encoding of their hierarchical arrangement in the Description of Map Units (DMU). See the NCGMP09 design (this volume) for a more thorough example drawn from a more typically complex DMU.

DMU_HIER	UNIT_NAME
001	Alluvial sediments
001-001	Alluvial sediments, thin
001-002	Alluvial sediments, thick
002	Coastal zone sediments
002-001	Coastal zone sediments, mostly fine-grained
002-002	Coastal zone sediments, mostly medium-grained
003	Calcareous biological sediments
004	Organic-rich sediments
004-001	Organic-rich muck and peat, thin
004-002	Organic-rich muck and peat, thick
005	Glacial till sediments
005-001-001	Glacial till sediments, mostly clayey, discontinuous
005-001-002	Glacial till sediments, mostly clayey, thin
005-001-003	Glacial till sediments, mostly clayey, thick
005-002-001	Glacial till sediments, mostly silty, discontinuous
005-002-002	Glacial till sediments, mostly silty, thin
005-002-003	Glacial till sediments, mostly silty, thick
005-003-001	Glacial till sediments, mostly sandy, discontinuous
005-003-002	Glacial till sediments, mostly sandy, thin
006	Glaciofluvial ice-contact sediments
006-001	Glaciofluvial ice-contact sediments, mostly sand and gravel, discontinuous
006-002	Glaciofluvial ice-contact sediments, mostly sand and gravel, thin
006-003	Glaciofluvial ice-contact sediments, mostly sand and gravel, thick
007	Proglacial sediments
007-001-001	Proglacial sediments, mostly fine grained, discontinuous
007-001-002	Proglacial sediments, mostly fine grained, thin
007-001-003	Proglacial sediments, mostly fine grained, thick
007-002-001	Proglacial sediments, mostly coarse-grained, discontinuous
007-002-002	Proglacial sediments, mostly coarse-grained, thin
007-002-003	Proglacial sediments, mostly coarse-grained, thick
008	Lacustrine and playa sediments
008-001	Lacustrine sediments
008-002	Playa sediments
009	Eolian sediments
009-001-001	Eolian sediments, mostly loess, thin
009-001-002	Eolian sediments, mostly loess, thick
009-002-001	Eolian sediments, mostly dune sand, thin
009-002-002	Eolian sediments, mostly dune sand, thick
009-003	Eolian sediments on southern High Plains
010	Mass-movement sediments
010-001-001	Colluvial sediments, discontinuous
010-001-002	Colluvial sediments, thin
010-002	Colluvial and alluvial sediments
010-003	Colluvial sediments and loess
010-004	Colluvial sediments and residual material
011	Residual materials
011-001	Residual materials developed in igneous and metamorphic rocks
011-002-001	Residual materials developed in sedimentary rocks, discontinuous
011-002-002	Residual materials developed in sedimentary rocks, thin
011-003	Residual materials developed in fine-grained sedimentary rocks
011-004-001	Residual materials developed in carbonate rocks, discontinuous
011-004-002	Residual materials developed in carbonate rocks, thin
011-005	Residual materials developed in alluvial sediments
011-006-001	Residual materials developed in bedrock, with alluvial sediments, discontinuous
011-006-002	Residual materials developed in bedrock, with alluvial sediments, thin
011-007-001	Residual materials developed in bedrock, discontinuous
011-007-002	Residual materials developed in bedrock, thin
012-001	Basaltic and andesitic volcanic rocks
012-002	Rhyolitic volcanic rocks
013	Water

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The Cookie Cutter: A Method for Obtaining a Quantitative 3D Description of Glacial Bedforms

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Introduction

Glacier bedforms, in particular drumlins, are visually distinctive landforms that have had a long history of study, with a particular early focus upon their location and distribution (Close, 1867; Charlesworth, 1924). Processes responsible for their genesis remain enigmatic, and there is no single, overarching theory of formation. Considerable work has focused upon drumlin parameterization (Smalley and Unwin, 1968) and internal composition in an attempt to describe and classify them. Research on drumlin morphology has also examined the role of glacier/bed interactions and bed preservation (Rose and Letzer, 1975) with a view to understanding and deciphering the landform record of multiple ice flows (Rose and Letzer, 1977; Boulton and Clark, 1990).

During this period, technological advancements in the derivation of surface morphology and data storage and analysis have enabled the gathering of larger datasets over shorter time scales and in greater detail (Clark, 1997). Despite these improvements, the three-dimensional (3D) quantification of glacial bedforms has received little attention, although this property is important for determining the relief and volume of bedforms. These are fundamental properties required for quantifying the amount of sediment moved by glaciers beneath an active ice sheet. In this poster (fig. 1) we show a newly developed methodology for characterizing the relief and volume of drumlins, apply the method to a test area, and discuss potential sources of error. The work is reported in full by Smith and others (2009).

Methodology

We propose a three stage procedure for the calculation of landform volume: Stage 1 involves initial mapping to identify and outline landforms; Stage 2 defines landform relief; and Stage 3 calculates individual landform volumes. Stage 1 requires scientific judgment, whilst Stages 2 and 3 are automated. All processing is performed within a geographic information system (GIS).

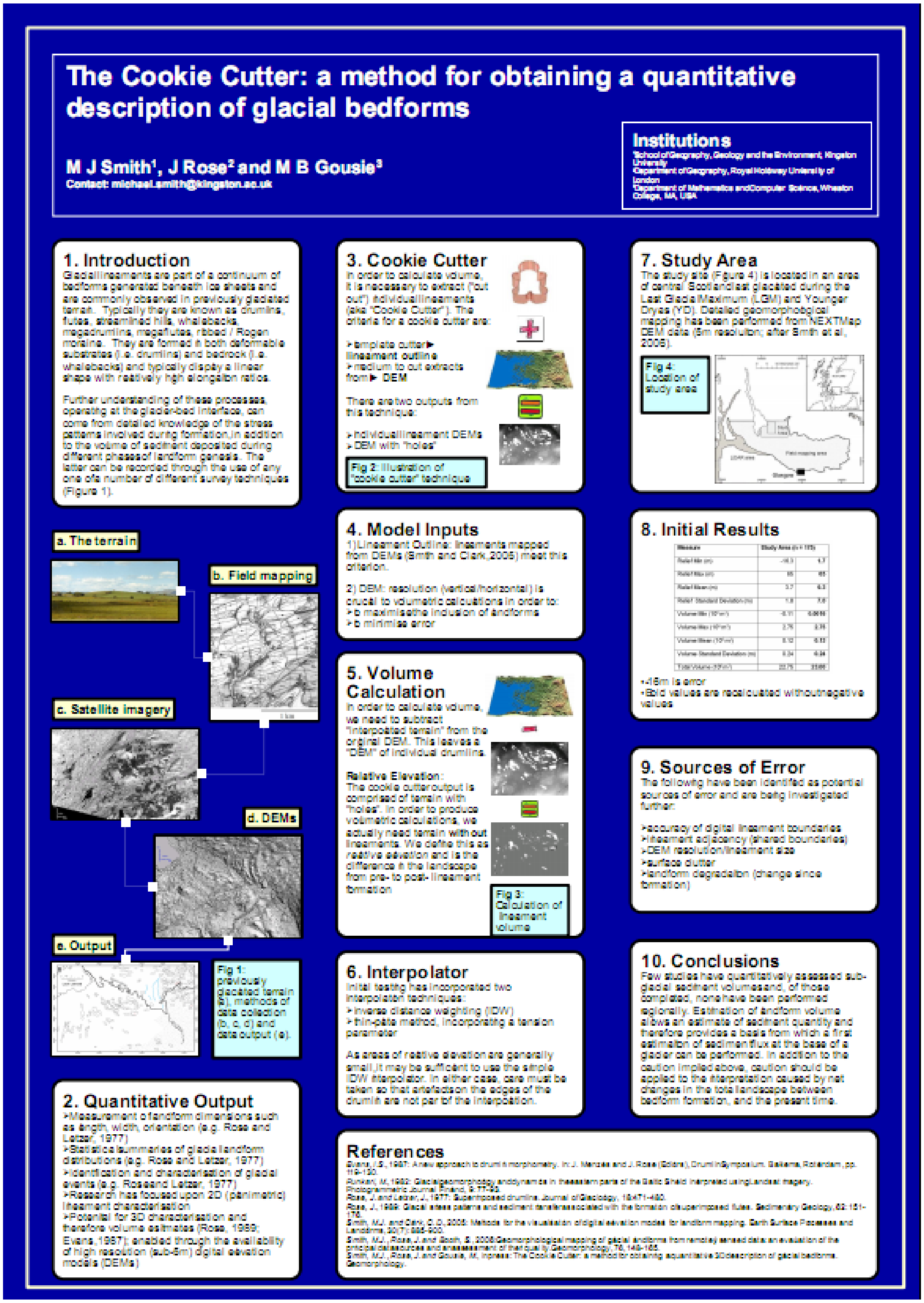

Figure 1. Extraction of 3D properties of glacial bedforms using interpreter mapping as input to an automated computer script ("Cookie Cutter") (presented as a poster; see full-resolution image at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Smith2.pdf*).

An input digital elevation model (DEM) is used to facilitate visualization of the terrain before the outlines of the drumlins are manually digitized (Smith and Clark, 2005). The area within the outline is then removed (the “cookie cutting” process) to produce a new DEM with “holes” or voids. A planar surface is then interpolated across each of the voids, using a thin plate spline, to leave a new “infilled” DEM. This is then subtracted from the original DEM, leaving a DEM of drumlin relief. Volume is calculated using drumlin area and height.

For this study, the NEXTMap Britain™ DEM (see *http://www.intermap.com/nextmap-britain*) is used as the data source for geomorphological mapping and subsequent calculations of drumlin relief and volume (Smith and others, 2006). NEXTMap is a single-pass interferometric synthetic aperture radar (IfSAR) product, with a spatial resolution of 5 m and a vertical accuracy of 0.5–1 m (Intermap, 2005).

Results and Conclusions

This poster presents a technique for the calculation of material volumes of drumlins from sites in western central Scotland. The method can be applied to other glacial bedforms and indeed to any landform. Digitized drumlin outlines are used to extract (“cookie cut”) landforms from an underlying DEM, leaving empty voids. The voids are “infilled” through the application of a tensioned spline interpolator thereby estimating the basal surface. Drumlin relief is then calculated by subtracting the basal surface from the original DEM and then converting it to volume by multiplying by the planform area. In order for the interpolator to operate using “edge” pixels surrounding each void, it is necessary for drumlins to be processed individually.

Using the above methodology, a protocol is established for the calculation of material volumes for similarly wholly concave or wholly convex landforms. The results presented in the poster provide a first-order approximation that facilitates the rapid calculation of drumlin volume. It is important to note that volume calculations are subject to error from the source DEM, digitization procedure, and presence of surface clutter, in addition to geomorphological problems inherent in the sample studied. This technique can potentially be used wherever landform volume estimates are required, for example, calculations of sand dune volumes or sediment input to depositional environments.

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Feature Extraction from High-Resolution Lidar: The Next Generation of Base Maps

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Introduction

The Oregon Department of Geology and Mineral Industries (DOGAMI) is the founding and primary member of the Oregon Lidar Consortium (OLC). The OLC has acquired approximately 4,000 square miles of publicly licensed, high resolution lidar topography in Oregon as of May 2009, and will have more than doubled that coverage by the end of the calendar year.

DOGAMI is the State agency charged with producing maps and reports of geologic phenomena and risk associated with natural hazards, such as tsunamis, landslides, coastal erosion, riverine floods, earthquakes, and volcanics. In an effort to produce work of the highest possible quality, virtually no new mapping of geology or natural hazards is undertaken without complete lidar coverage. While recently acquired lidar is beneficial in most cases, it does cause problems when producing base maps on which to present geologic and natural hazard data. The fundamental problem is that lidar is much more spatially accurate than other data sources and that when thematic layers are overlaid, misalignments abound. Some initial solutions are proposed by Burns (2008). The following is a description of several advanced methods for extracting thematic layers directly from the lidar.

Bare Earth DEM

Raw Elevation Model

The bare earth digital elevation model (DEM) is a representation of the Earth's surface stripped of manmade objects and vegetation (fig. 1). This is achieved through post-processing of lidar point data, where the sheer density of elevation points collected -- in this case, upwards of 8 points per square meter -- allows for the recognition of high-precision (submeter) ground trends. Within the geology community, bare earth elevation models have proven revolutionary in their ability to reveal the subtleties of terrain, shedding light on previously unidentified features such as alluvial fans, landslides, and historical channel beds. The power of the bare earth elevation model to aid in understanding terrain is further examined here through various strategies in geovisualization.

Customized Hillshading

Hillshading brings an elevation model to life. However, every terrain is unique, so why illuminate them all the same way? In this example we shift the light source from its standard 315 degrees azimuth and 45 degrees declination to 345 and 60, respectively (fig. 2). Also, we exaggerated the vertical by a factor of 5. This landscape is dominated by northwest-trending drainages, and so specifying the light source farther northward better defines their features. Exaggerating the elevation in an area with such high relief also helps to bring out its nuances.

Defined Slopes

While hillshading is truly essential for visualizing terrain, its inherent directional biases often shroud useful detail that lies in shadow. An effective method for accenting all slopes is by draping a semitransparent hillshade over a slope layer, where the highest slope values are represented by a dark color (fig. 3). It is also useful to exclude low slope values when classifying the slope layer, since they are not especially useful and have a tendency to muddy up the look of the map.

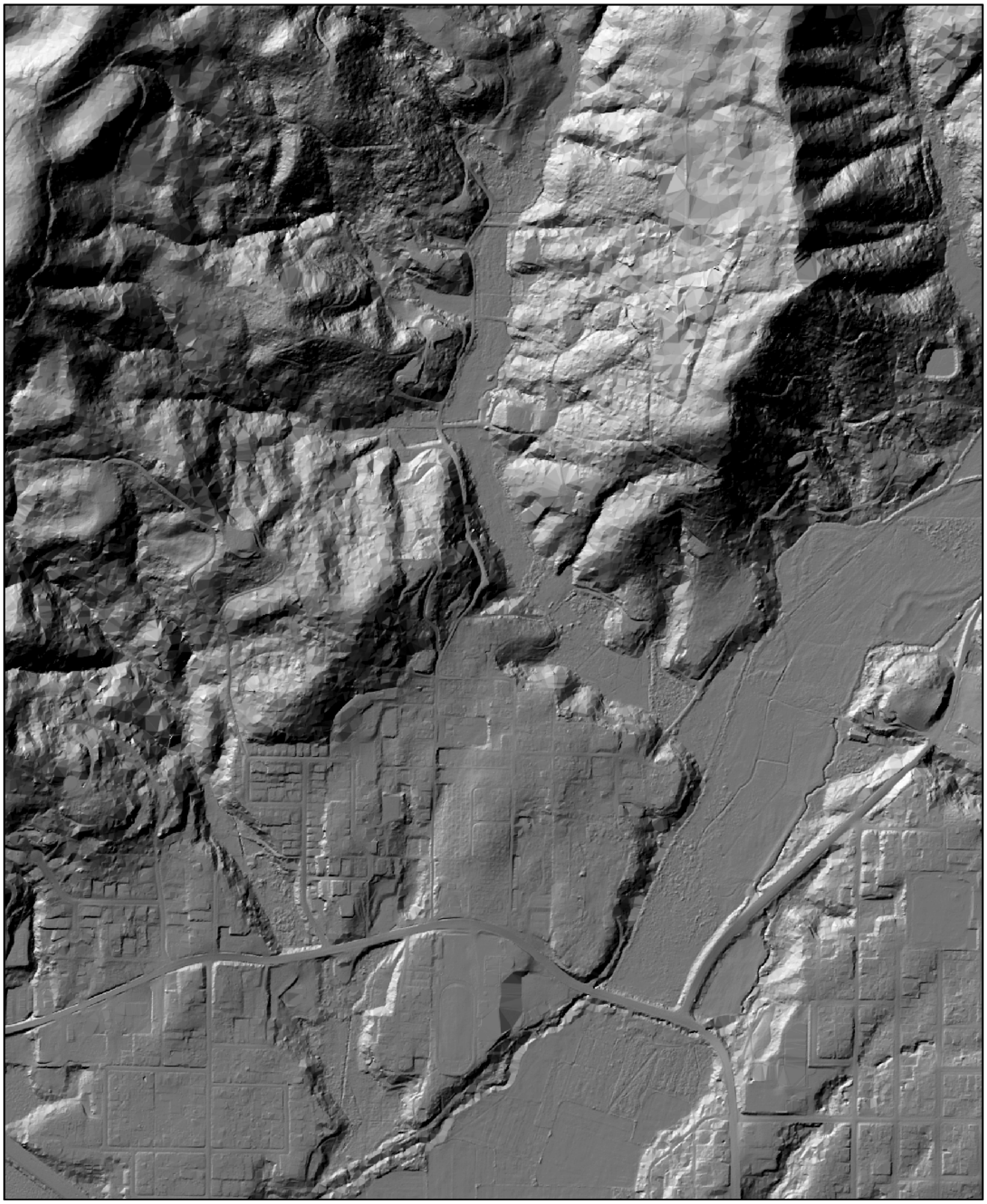

Figure 1. Bare earth lidar with standard hillshading (315 degrees azimuth and 45 degrees declination). The area featured here is a portion of the city of Coquille, Oregon.

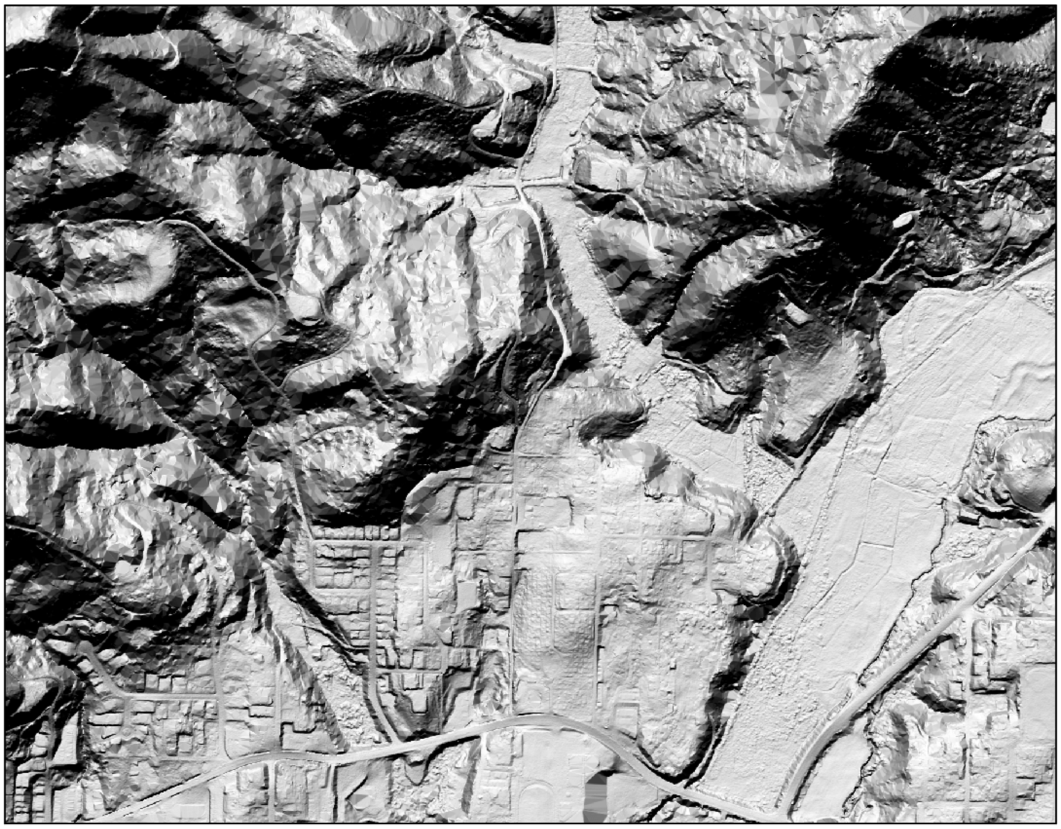

Figure 2. Bare earth lidar with customized hillshading (345 degrees azimuth and 60 degrees declination, and 5X vertical exaggeration).

Figure 3. Bare earth lidar with customized hillshading and defined slopes.

Smoothed Contours

Contours minimize guesswork when interpreting elevations. With lidar it is possible to effectively contour a terrain with 2-foot intervals. At smaller scales, though, such exquisite detail becomes a visual liability. To massage out some of this detail and produce more appealing and appropriate contours, try smoothing your bare earth elevation model by averaging its values over a set radius, and then build your contours from there. These contours have an interval of 20 feet with indices every 100 feet (fig. 4).

Figure 4. Bare earth lidar with customized hillshading, defined slopes, and smoothed contours.

Hydrology Delineation

Numerous valiant attempts have been made toward automating the extraction of hydrologic features from lidar. Nonetheless, we find that there is no substitute for the trained eye and a steady hand. Using a combination of bare earth hillshade and slope as a base layer produces accurate stream and water body delineations on the first try, with no clean-up of erroneous (and often ample) vertices (figs. 5 and 6). Orthorectified aerial photos can be used to verify hydrologic features where they are unclear in the lidar.

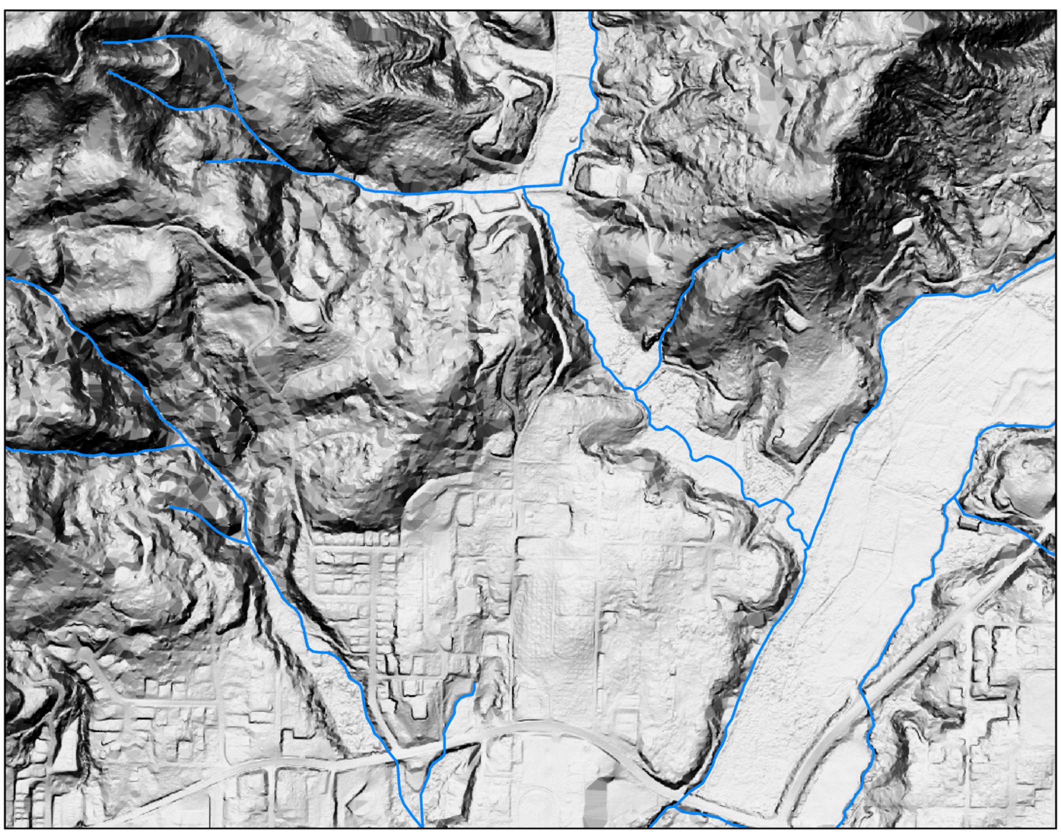

Figure 5. Bare earth lidar with customized hillshading, defined slopes, and hydrology (blue lines).

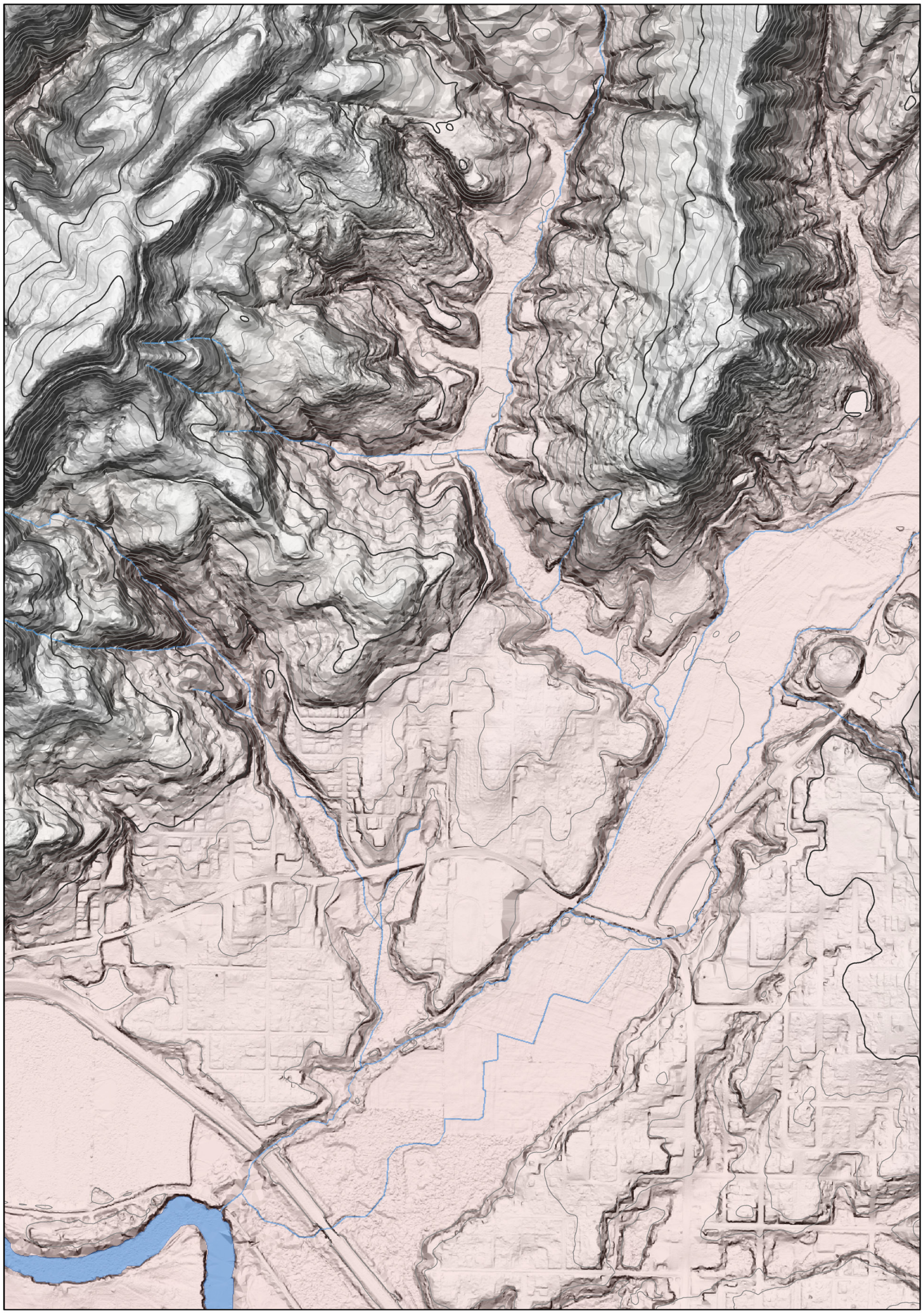

Figure 6. Composite bare earth lidar image.

Highest-Hit DEM

Raw Elevation Model

The highest-hit elevation model is a representation of the full-featured landscape at the time of the lidar aerial survey (fig. 7). As opposed to the last-return (ground) illustrated by the bare earth elevation model, the highest-hit is the first-return to the lidar sensor -- be it tree, car, skyscraper, or even people. Though not as immediately useful for applications in geology as the bare earth elevation model, it has many merits when it comes to feature extraction for base mapping.

Figure 7. Highest-hit lidar with standard hillshading.

Structure Modeling

With some simple math we can approximate flat-topped structures (for example, buildings). First we subtract bare earth from highest hit. This gives us the heights of all raster cells considered "non-ground." We can further refine this by taking the slope of our "non-ground" layer and isolating those areas with low slopes -- say below 25 degrees. In general, these areas will represent buildings and bridges (fig. 8). Additional tricks in symbology can be employed to reduce the appearance of non-buildings.

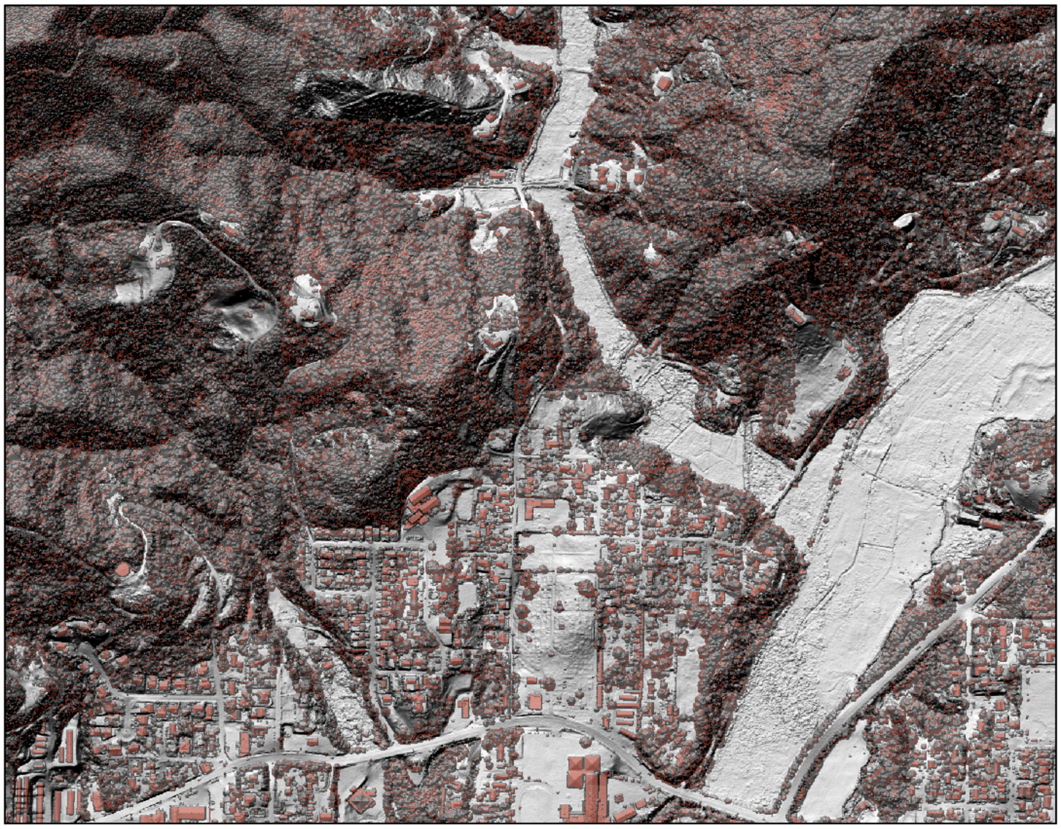

Figure 8. Highest-hit lidar with customized hillshading and structure model.

Canopy Modeling

Similar to structure modeling, using a "non-ground" layer we can approximate trees and other vegetation. This time we are interested in isolating features with a rather high slope. We can then take one step further by symbolizing "non-ground" height values from a light green (shrubs) to a dark green (tall trees). The result is a very visually appealing layer that illustrates the varying heights of trees in particularly well forested landscapes (fig. 9).

Figure 9. Highest-hit lidar with customized hillshading and canopy model.

Building Extraction

Structure modeling can be further extended to true building extraction. With the help of Lidar Analyst software (by Visual Learning Systems), we can create polygons that accurately represent building footprints with very little or no editing. Lidar Analyst uses breaks in slope, recognition of angles, and supervised classification to produce polygons that are attributed with z-values -- very useful for 3D visualizations. This tool, in concert with structure and canopy modeling, creates an extremely realistic view of a landscape without use of aerial photos (figs. 10 and 11). It is worth noting that building extraction differs from hydrologic feature extraction in that the resultant vector layer is much less vertex-rich and therefore less painstakingly edited.

Additional Notes

These data were collected with a Leica ALS50 Phase II Lidar system (150 kHz). Pulse density is at least 8 points per square meter with vertical accuracies within 15 centimeters on flat surfaces. Raw data were gridded to 1-meter resolution. The town of Coquille, Oregon, is shown on these maps. All maps are represented at a scale of 1:8,000. Maps projected in Universal Transverse Mercator (NAD 1983) Zone 10 North. All geoprocessing was performed using ESRI ArcGIS products.

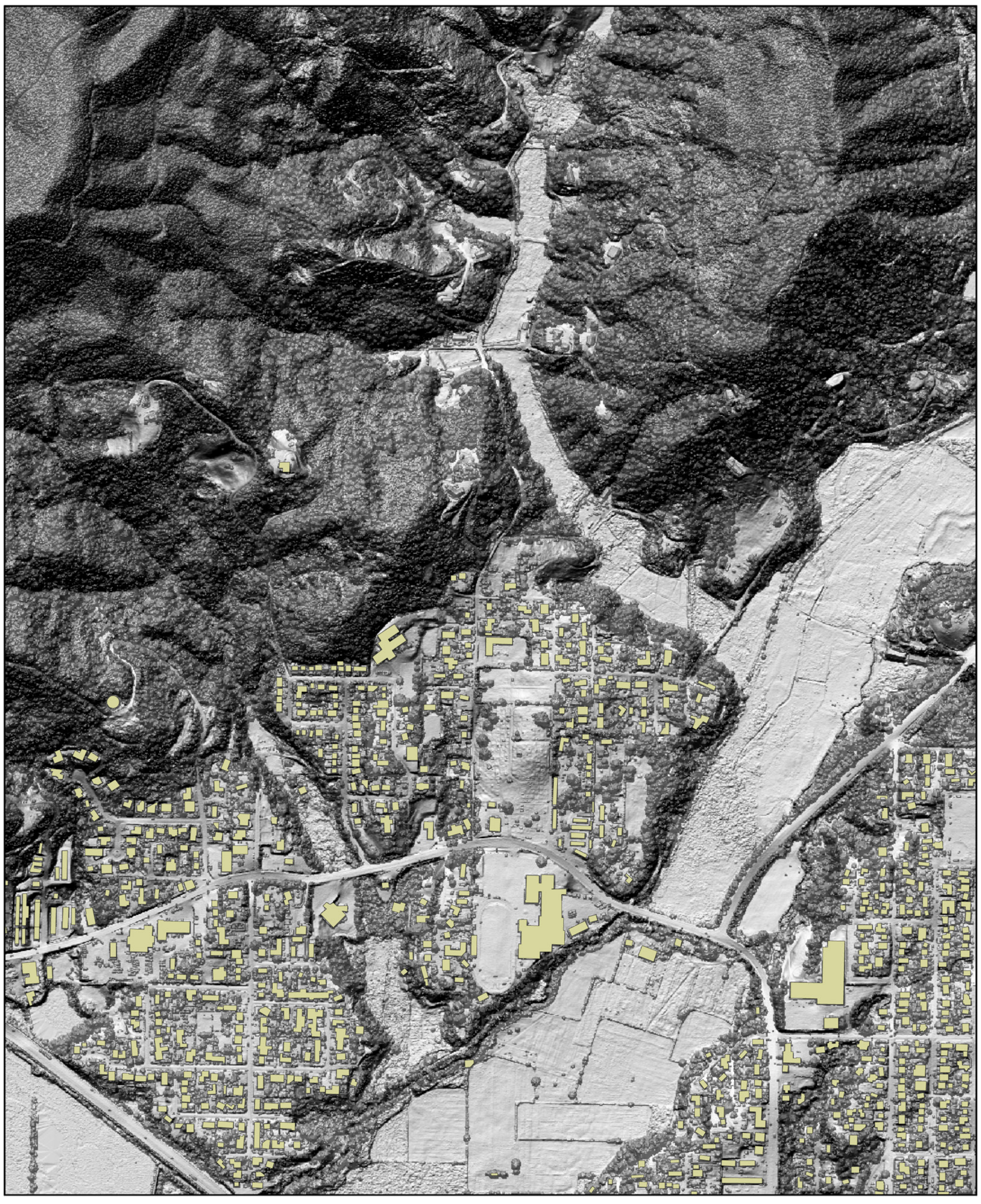

Figure 10. Highest-hit lidar with customized hillshading and extracted buildings (in yellow).

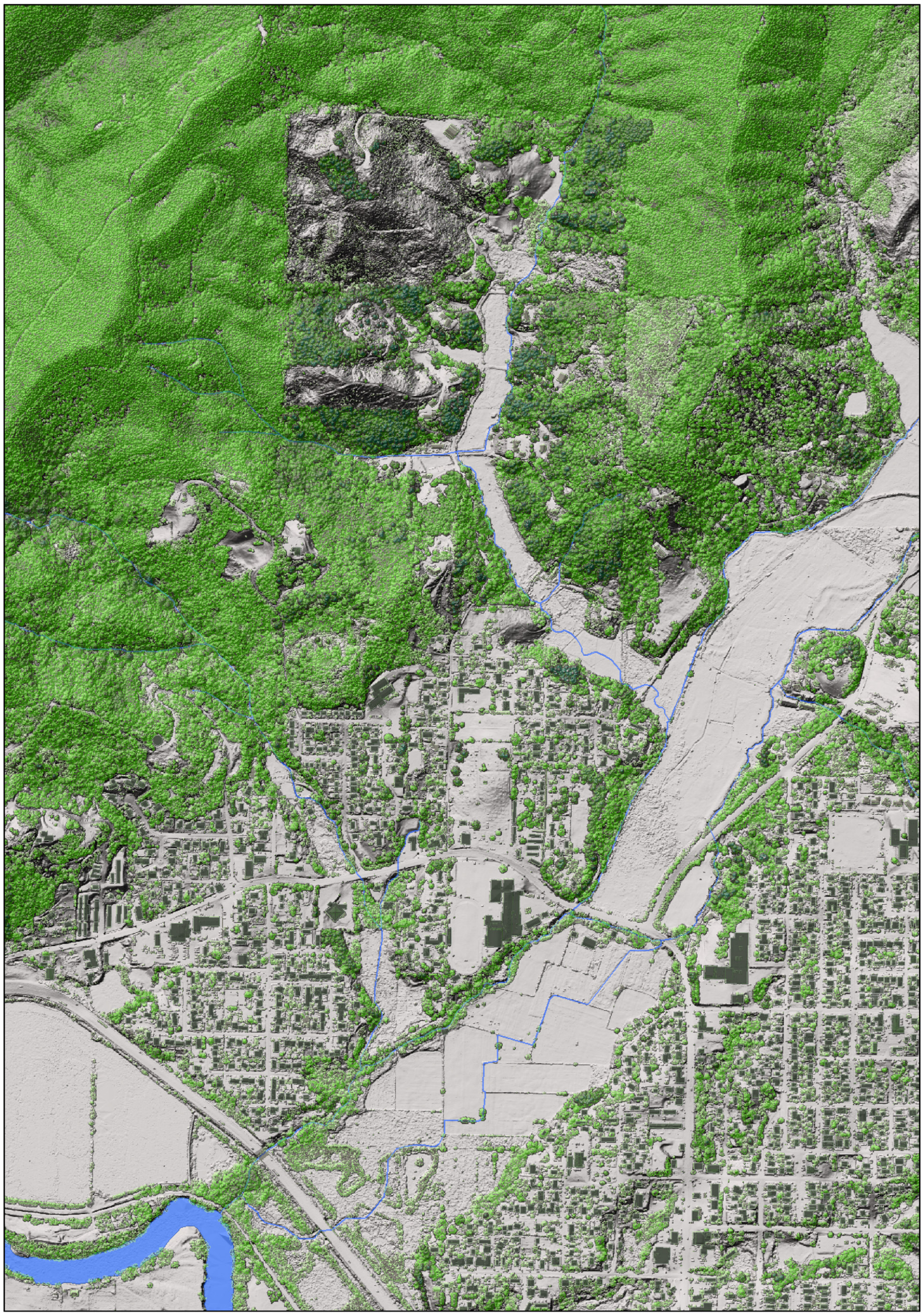

Figure 11. Composite highest-hit lidar image (with extracted buildings, not structure model).

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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 '<u>geologic unit</u>', '<u>map unit</u>', and '<u>mapped feature</u>' as follows. *<u>Geologic units</u>* represent particular (location situated) bodies of rock in the Earth (NADMSC, 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/*). *<u>Map units</u>* 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 *<u>Mapped feature</u>* 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 NGDMB-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 straigraphic 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.

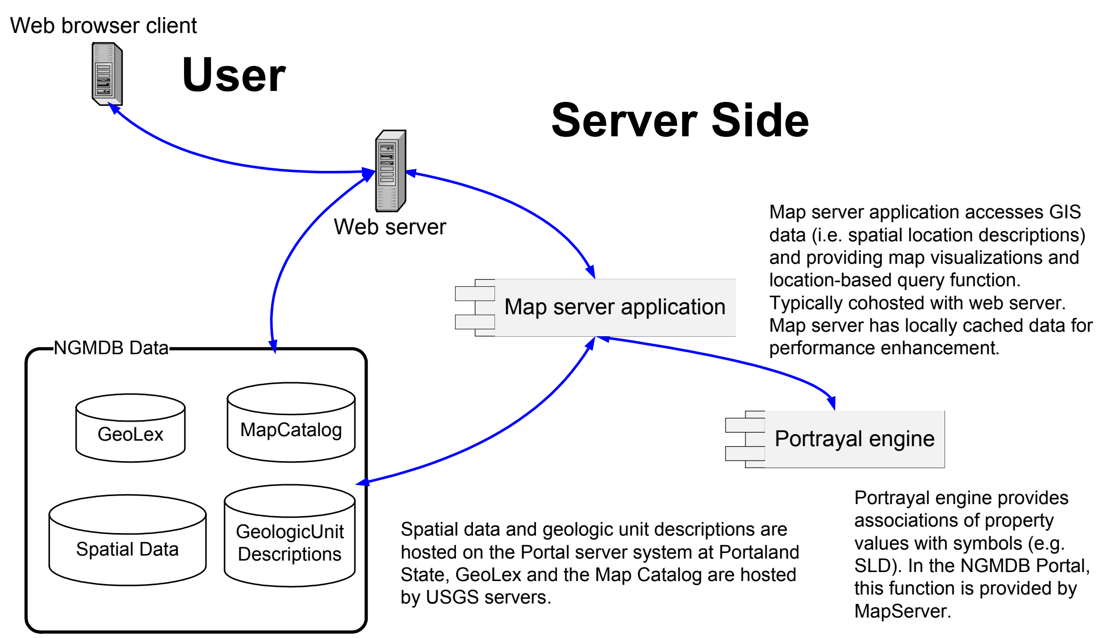

Figure 1. Diagram of basic system architecture. The portal client application runs in a Web browser on the client machine, accessing a Web server using standard HTTP protocol. The Web server sends map display requests to the Mapserver application, which retrieves the geometries for the spatial objects 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.

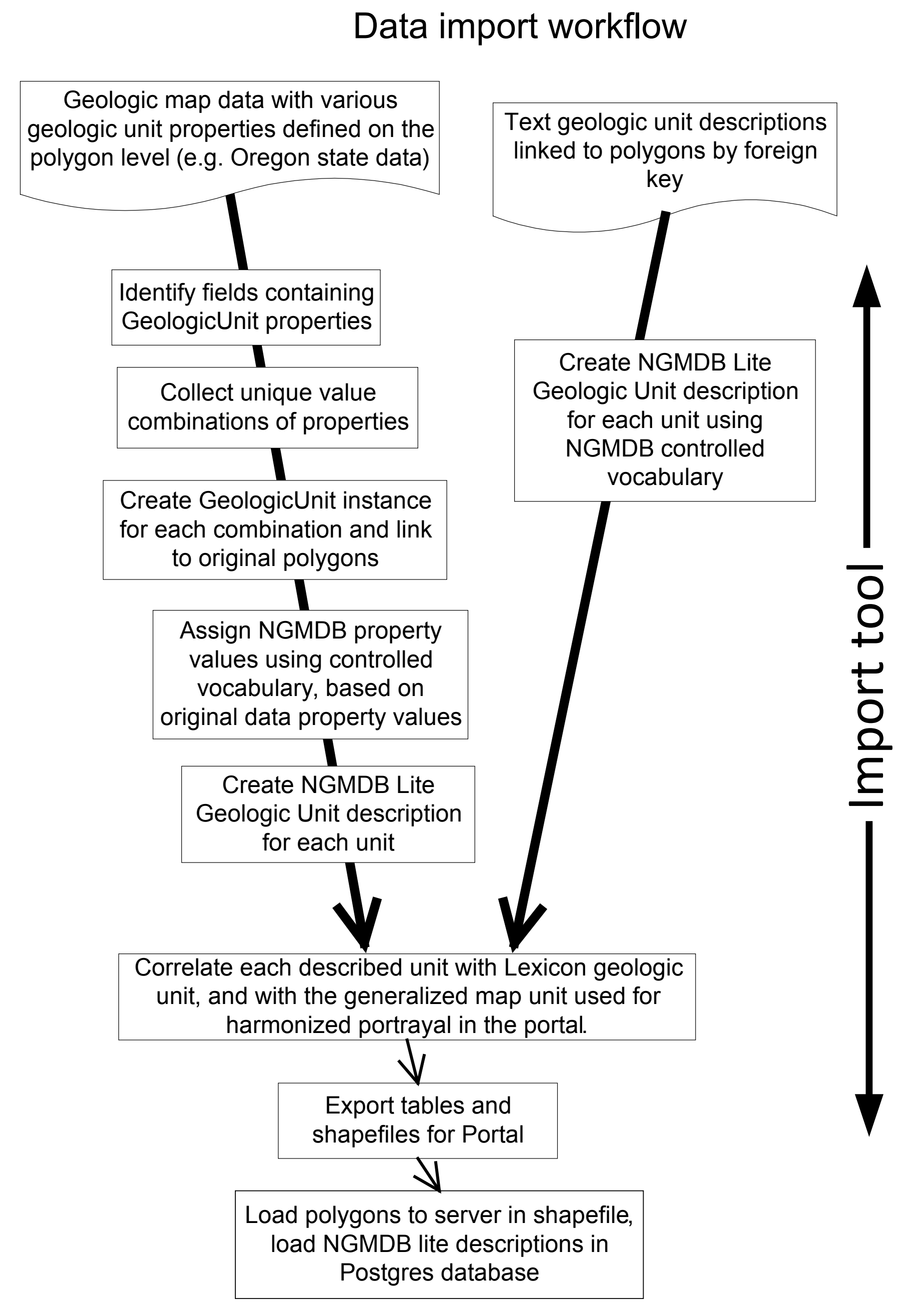

Figure 2. Two workflows, to process geologic information on maps or in databases that occurs in various formats with nonstandardized vocabulary, in order to produce standardized data in NGMDB-Lite. The workflow for nonnormalized data is shown in the left branch of this figure, and the workflow for normalized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

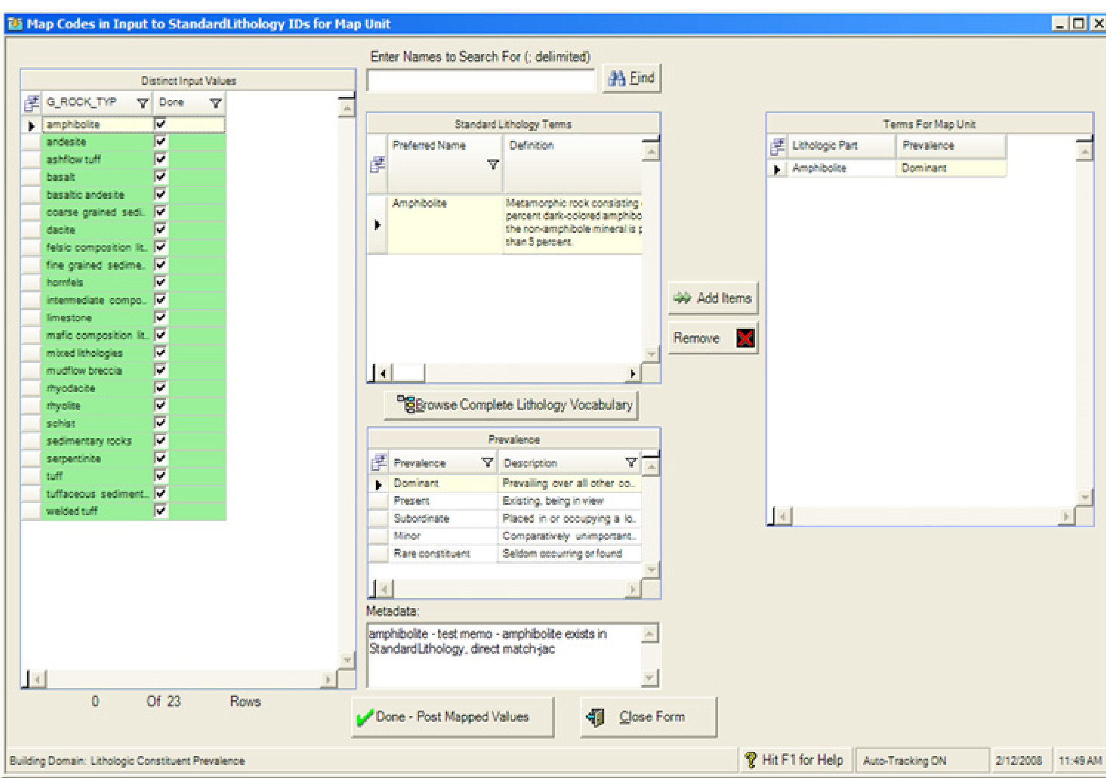

Figure 3. Screen shot of NGMDB data entry tool window, opened to the form used for mapping from a unique value or combination of values in the source data into the lithology category scheme for the NGMDB Data Portal. In this example, the source is derived from only one field in the source dataset. The 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/geosciml.html*) 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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Development of an ArcGIS Map Template to Support Standard Geologic Map Production in Kentucky

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Overview

The Kentucky Geological Survey (KGS) first used the ESRI ArcMap template for the Fiscal Year 2007 U.S. Geological Survey STATEMAP surficial geologic mapping deliverables. Several mappers were working on eight geologically similar 7.5-minute quadrangle maps in the Ohio River Valley of western Kentucky. This region of Kentucky includes Pleistocene lacustrine, glacio-fluvial outwash, and alluvial floodplain deposits, with bedrock-cored uplands typically mantled by loess (fig. 1). Processes during the evolution of the Ohio River Valley affected all the tributaries during flooding and erosion. Therefore, the deposits are similar in material, age, and sequence within the study area. To understand this complex region and prepare maps useful to other disciplines, a regional research strategy was used. Soil boring sites were selected to examine the vertical variability of all the deposits within the region, regardless of quadrangle boundaries. Since geologic map units were developed for the entire region, KGS chose to reflect this regional perspective on each published map with a diagram showing the correlation of map units. This allowed all regional map units to be included in a template that contained all possible map unit symbol boxes filled with an appropriate color from an ArcMap style file. A customized ArcMap template was used to make map production more efficient for the geologists and to ensure standard cartographic styles across the region. The USGS Geologic Map Style Guide, version 1.4 (2004), and the FGDC-STD-013-2006 (FGDC, 2006) cartographic standards were used to the extent possible in the design layout of the template. All mappers considered this appropriately designed template to be an efficient way to standardize map elements and minimize their cartographic effort.

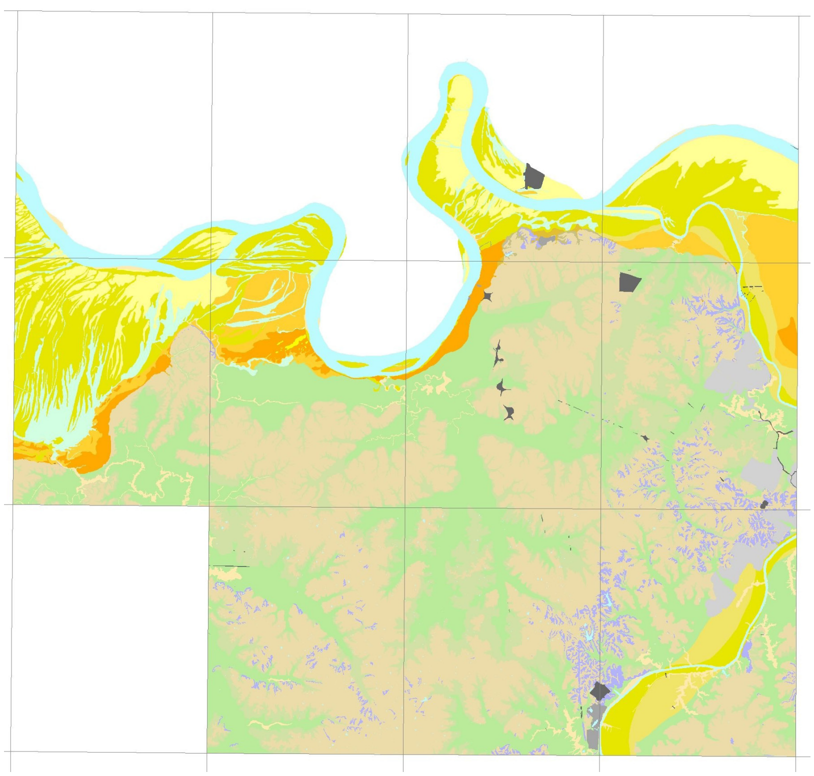

Figure 1. Regional map of the Ohio River Valley of western Kentucky showing the extent and continuity of the deposits in this 11-quadrangle area.

Template Design

Every ArcMap document, by default, opens with a blank virtual layout page and one empty data frame. After data are entered into the data frames, the data frames are added to the appropriately resized layout page along with other map elements such as legends and scale bars. Ordinarily this document is saved and becomes a map document; however, it can also be saved as a custom template and selected in place of the default template when opening ArcMap. KGS designed a custom template to contain all of the standard cartographic elements common to each individual quadrangle (fig. 2). The layout of the template contains five data frames, into which are inserted shapefiles (or geodatabase layers) containing the geologic map, a cross section, quadrangle location, quadrangle index map, and the correlation of map units illustration. The template also contains other graphic and text elements for adding or customizing the map collar information. The position and spacing of each element, as well as title and font specifications, conform to the USGS style guide. Most of the collar elements contain default text stored as a Word file; some text documents are edited for each map by clicking on the embedded Word file, while other text files are standard for all maps. The description of map units contains descriptions that are generalized for the entire region and map unit symbol boxes that contain a standard legend color. The colors are assigned by the geodatabase to an attribute value, through an ArcMap style file that is referenced with the template design.

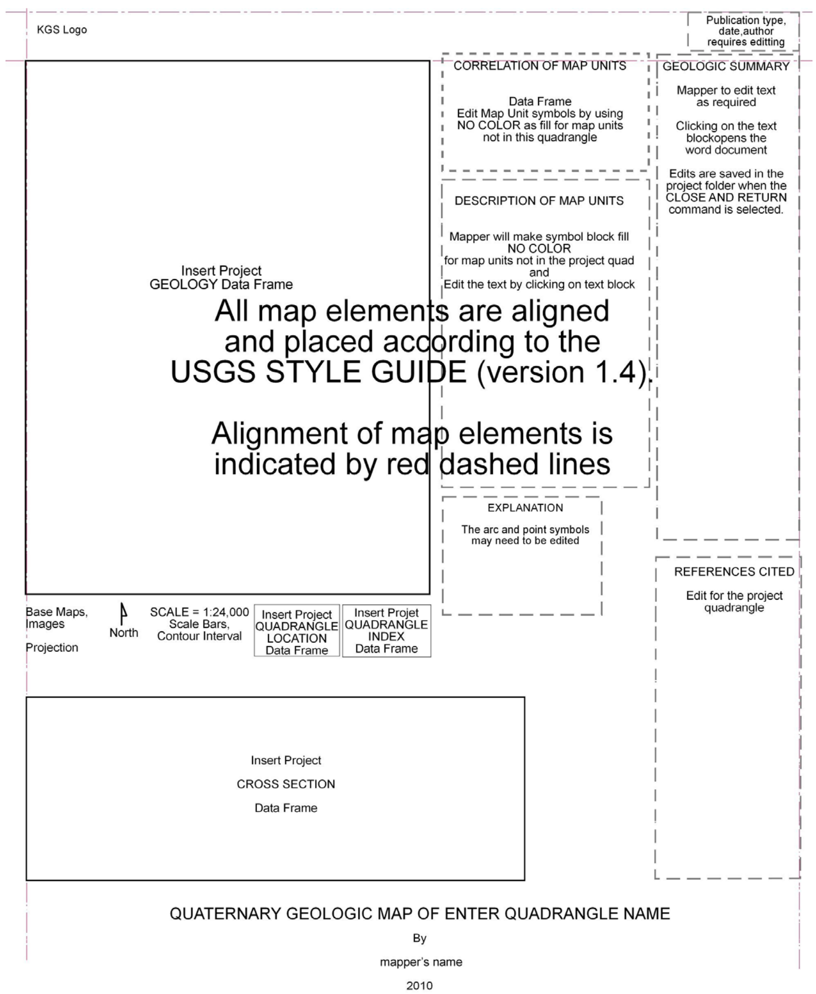

Figure 2. ArcMap template with position and type sizing of standard elements to be added by each mapper.

Template Use

Each mapper opens a new ArcMap project by specifying the custom template. Simple text edits are then made, such as the title, authors' names, publication number, and corner coordinates for the specific map area. The authors then add and edit text, as required, for the description of map units, geologic summary, and references sections, within each designated area of the template. Editing the text ensures the formatting is retained. Any new text must be formatted by the mapper. This is done by the mapper with these steps in ArcMap: in the project Layout View use the "Insert" tool, select "Object", click "Create from File", use "browse" to access the template text folder and select a text block that is correctly formatted, then properly place this object into the Layout View. Double click this text block in the layout view to open the Word-formatted text, edit the text, and select "Close & Return to project.mxd". Data such as shapefiles, annotation, and imagery are added to the geology, cross section, quadrangle index, and quadrangle location data frames (the correlation of map units shapefile is the same for all maps of the region). The custom style file is used to symbolize the arcs and polygons of the legend, the map unit symbol boxes in the description of map units, and the geologic map and cross section data frames. This approach ensures standard color assignments across the region and within the map. It also serves to validate the attribution of the shapefiles, because any errors in attribute assignment to arcs or polygons will show on the map or cross section with an incorrect color, and misspelled attribute values will be assigned the color for "other" in the ArcMap legend. These errors are readily apparent, and are then corrected. Although all of the map unit descriptions for the region are retained in the final publication of each quadrangle map, those that do not occur on a particular map must have their colors removed in order to indicate that they are shown only for context. Figure 3 shows part of the geology and correlation of map units data frames, with the appropriate edits, for a specific map. Note that the correlation of map unit symbol boxes Qao, Qafp, Qot1, Qot2, and QTg do not have color fill.

Developing an ArcMap template requires significant set-up time by someone familiar with the design process. The ESRI template is designed so that only the designer of the template can edit the template or associated text files. All map-specific customizations are stored in the user's local map project folder.

Each mapper estimated that the 2006 deliverable map, which was done without using the template, required at least 3 weeks for cartography. For the 2007 deliverables, using the template, the mappers prepared the cartography in 3 days or less.

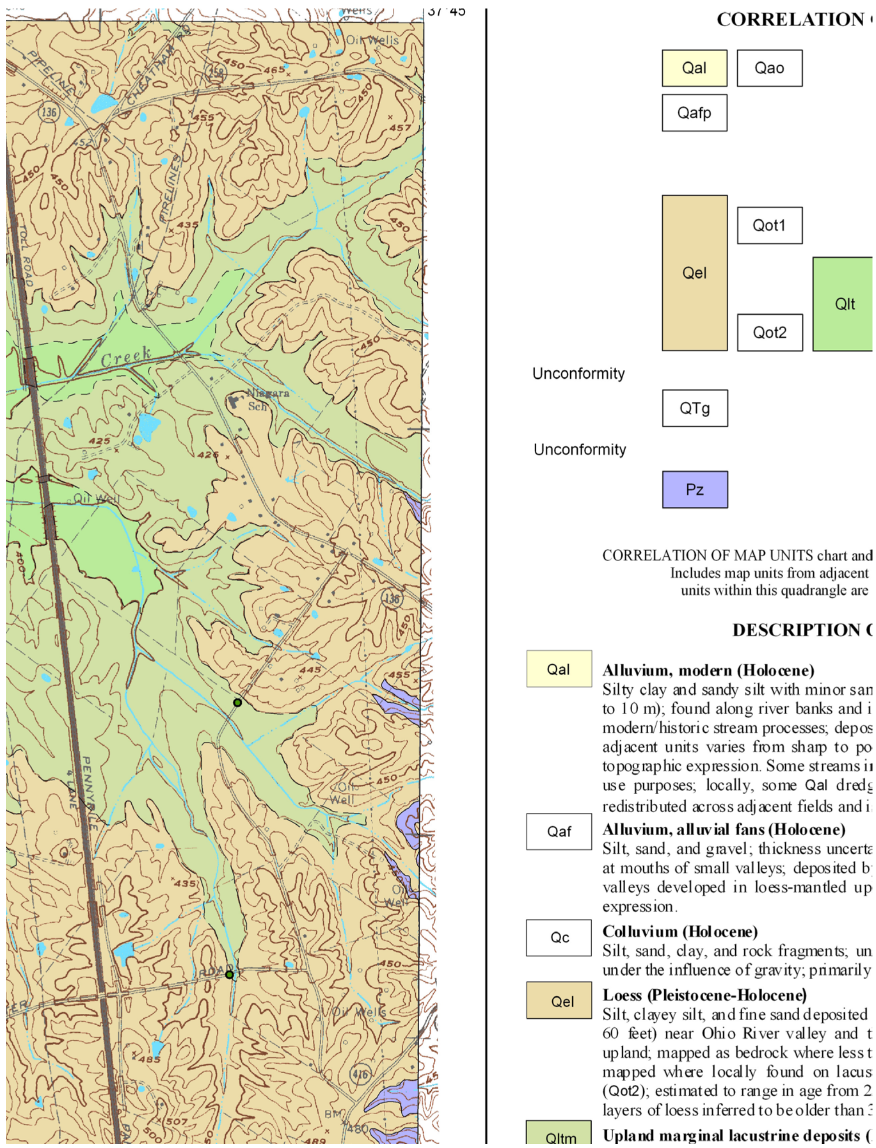

Figure 3. Detail of a completed map at 1:24,000 scale, showing parts of the Geology and Correlation of Map Units data frames modified for this particular quadrangle.

Standards

KGS developed this template and associated style file prior to the formal release of the ESRI implementation of the FGDC cartographic standard. KGS followed the new FGDC cartographic standard, in spirit. This standard specifies the symbols in decimal millimeter units, but the ArcMap Line Symbol creation menu specifies symbols in picas. Because picas are in whole units, whereas millimeters are not necessarily so, converting between picas and decimal millimeters required deviation from the standard. Therefore, the lines generated by KGS are not exact replicas of those in the FGDC standard, but follow in intent.

Line styles in the Legend, in close proximity, are readily distinguishable. However, these same lines, when distanced on the map, may closely resemble several different lines depicted in the Legend, causing uncertainty as to which symbol is being indicated. KGS followed a draft FGDC symbol style file provided by T.A. Lindquist, USGS (personal communication, 2008). Ms. Lindquist warned that ESRI may use a different computer process/language for future symbol generation. Therefore, only a limited number of replicated FGDC symbols were entered into the KGS style file for testing. The names of selected styles were abbreviated for the KGS attribute table, in order to accommodate ArcPad applications.

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New GIS Tools for Mapping Ohio's Lake Erie Coastal Erosion Areas

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Abstract

Every 10 years, the Ohio Department of Natural Resources (ODNR), Division of Geological Survey identifies and maps coastal erosion areas along Ohio's 262-mile Lake Erie shore. Coastal erosion areas are those likely to erode over the next 30 years if no additional shore protection is emplaced. Historically, eroding bluffs and shores have caused considerable economic damage to property, buildings, and public infrastructure. The objective of the Coastal Erosion Area (CEA) Program is to minimize economic losses by ensuring that new development along the Ohio shore is adequately protected from coastal erosion.

To perform mandated remapping of coastal erosion areas, the ODNR Division of Geological Survey developed three new GIS applications. The first application assigned identification numbers to shoreline intersections and shore-normal transects, which ensured a unique, contiguous series of identification numbers that have a spatially sequential orientation. The second application allowed staff members to digitally map the 2004 shoreline intersections on high-resolution, orthorectified digital imagery that improved the overall quality and precision of the 2004 shoreline recession dataset. Finally, staff members translated the original FORTRAN 77 code into VBA and ArcObjects for ArcGIS® to create the third application, which automatically calculates the amount and rate of recession and the 30-year average recession distances for each shore-normal

transect. These applications facilitated the coastal erosion areas mapping effort and significantly reduced the time needed to complete the project. Moreover, the new coastal erosion area maps can now be distributed electronically to the public via Web site or a Web map service, and geospatially integrated with other coastal datasets such as property parcel ownership and shore-structure inventory datasets.

Shore Erosion along the Ohio Coast of Lake Erie

Erosion along the Ohio Lake Erie shore is a major geologic hazard that has significantly affected coastal residents. Erosion occurs as a result of the removal of material at the base of a bluff by wave action and the combined effects of gravity and groundwater, which erode the bluff face by slumping or debris flows or both. In areas of exposed bedrock, undercutting at the base of the bluff causes catastrophic failure and collapse of the bluff face into the lake. The rate at which the shore erodes is a function of the geologic composition of the shore, lake levels, prevailing winds, and the presence or absence of shore protection.

Shore erosion along Lake Erie can be either dramatic or relatively steady in nature. Between 1973 and 1990, the average shore recession rate was 1.41 feet per year, or approximately 24 feet over the 17-year period. Recession rates along the coast range from 0 feet per year to up to 56 feet per year along certain reaches of the coast. Large-scale changes can also occur. Near Painesville, Ohio, the coast has undergone between 34 and 207 feet of recession from 1973 and 1990 (fig. 1). The Sheldon Marsh barrier beach, which was overwashed and eroded during the great November 1972 storm (Carter, 1973), has undergone between 268 and 953 feet of recession over the 17-year time period (fig. 2). While these large-scale changes are very dramatic, relatively steady erosion rates along the coast are also a hazard, eroding bluffs and damaging properties. As a bluff recedes, buildings are lost by either falling into the lake, or being torn down before they are destroyed, or moved back from the bluff (figs. 3A and 3B).

Historically, shore erosion has caused a large amount of damage along the coast. Studies performed by the U.S. Army Corps of Engineers (1971) between the spring of 1951 and the spring of 1952 computed erosion-related damages along Ohio's Lake Erie shore to be $11.3 million. The most significant storm of the 20th century was the storm of November 14, 1972 (Carter, 1973), which caused approximately $22 million in damages (Environmental Data Service, 1972). An economic study of damages caused by coastal erosion shows that even if buildings are not damaged, property values decline rapidly when the home or building is within 25 feet of the bluff or shore edge (Kriesel and Lichtkoppler, 1989; Kriesel and others, 1993). A study performed by the ODNR Division of Geological Survey found that 25 percent of lakefront homes were within 25 feet of the bluff or shoreline, and another 22 percent were between 25 and 50 feet of the bluff or shoreline (Guy, 1999).

Given the proximity of homes to the shore, the State of Ohio developed the CEA Program to identify areas at risk to erosion along the Ohio shore. The objective of the CEA Program is to minimize economic losses by ensuring that new development along the Ohio shore is adequately protected from coastal erosion. The Ohio Revised Code (ORC 1506.06) states that the ODNR Director shall review and may revise the identification of the Lake Erie coastal erosion areas at least once every 10 years. Coastal erosion area maps identify areas at risk of being lost to coastal erosion over a 30-year period. Once coastal erosion areas are designated, the CEA Program requires a permit to construct or modify a habitable structure within a coastal erosion area. To receive a permit, a property owner must demonstrate that adequate shore protection is in place to protect the new structure from erosion.

The first designation of coastal erosion areas was finalized in 1998. The 1998 coastal erosion area mapping used uncontrolled aerial photography from 1973 and 1990 as the basis for measuring coastal erosion. The 1990 aerial photographs were enlarged to approximately 1:2,000 scale and printed onto a Mylar base. Shore-normal transects were drawn on the 1990 imagery, approximately 100 feet apart. These shore-normal transects serve as reference lines from which recession distances and rates are measured. The 1973 aerial photos were enlarged to the same scale as the 1990 images and the 1973 shoreline was then transferred to the 1990 imagery. Where the 1973 shoreline, the 1990 shoreline, and the 1990 toe of the bluff intersected the shore-normal transects, the intersections were mapped on the 1990 imagery.

The transects, the 1973 and 1990 shoreline intersections, and the 1990 toe of the bluff were digitized using SigmaScan® software, with each 1990 aerial-photo image having its own relative coordinate system. Once digitized, the vector data were then used as input into a FORTRAN 77 program that calculated (1) the recession distance and recession rate between 1973 and 1990 and (2) a smoothed 30-year average recession distance, that is, where the shoreline is projected to be in 2020. The 30-year recession (or coastal erosion area) distance was then plotted back onto the 1990 imagery (Mackey and others, 1996; Guy, 1999). The preliminary coastal erosion area maps were released to the public in 1996. After an extensive public notification and review process, the final coastal erosion area maps were approved by the ODNR Director in 1998 (fig. 4).

Gis Applications for the Updated Coastal Erosion Area Designation

The latest remapping of coastal erosion area designations involved three steps: (1) converting the 1998 coastal erosion area maps to a GIS (McDonald, 2009); (2) mapping of the 2004 toe of the bluff and the shoreline intersections at each shore-normal transect; and (3) calculating the new coastal

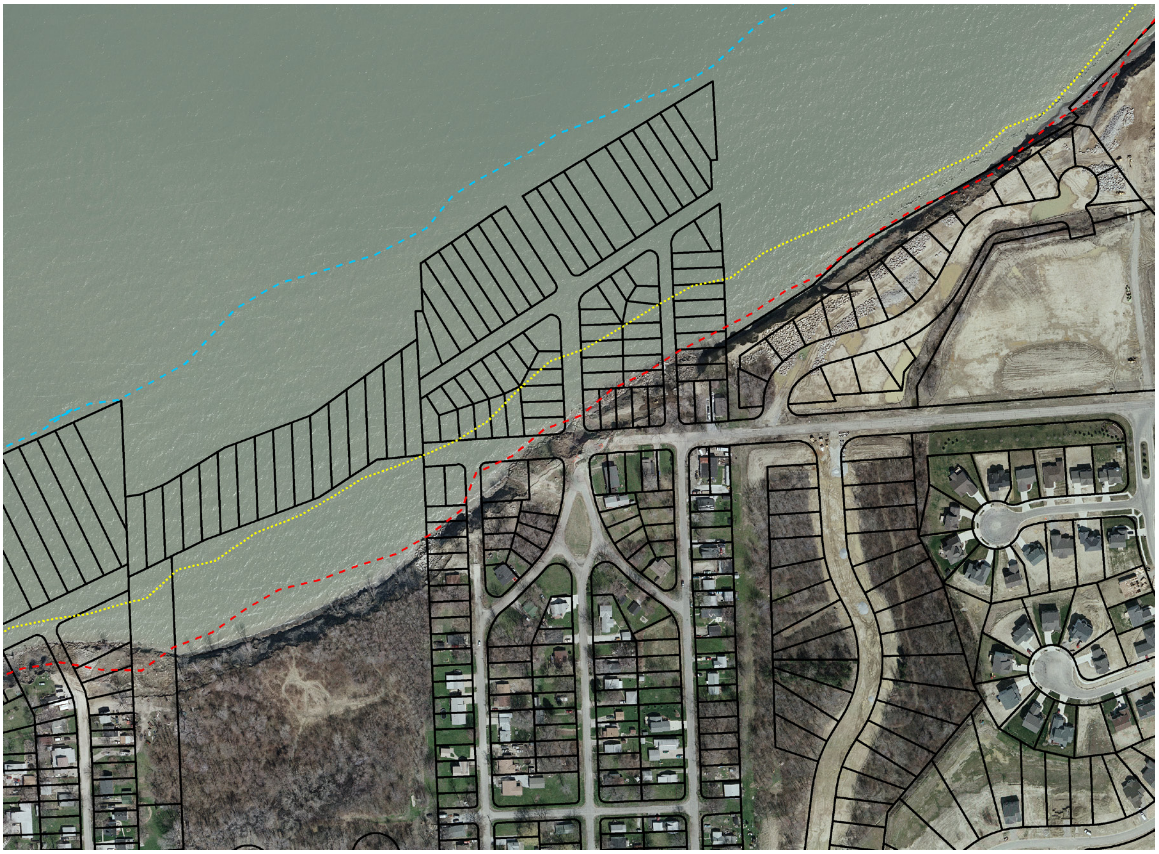


Figure 1. An area of the Lake Erie coast near Painesville, Ohio, that has undergone up to 207 feet of recession during the 17-year period. The blue dashed line indicates the 1876 shoreline; the yellow identifies the 1973 shoreline; and the dashed red line represents the 1990 shoreline. Aerial photo was taken in 2004. The black outlines are parcel boundaries. As can be seen, parcels have been lost due to coastal erosion.

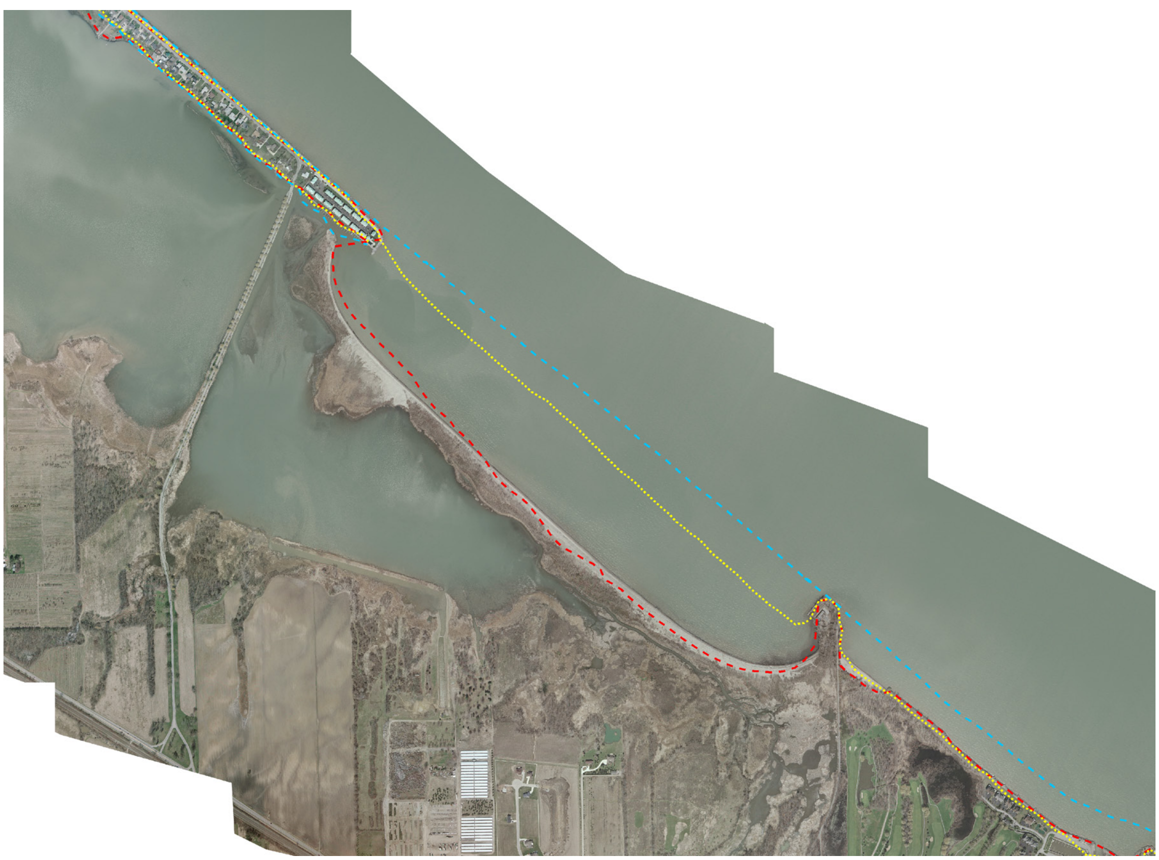


Figure 2. The Sheldon Marsh barrier island, which was eroded and moved landward during the great November 1972 storm, has been retreating at a rate between 15 and 56 feet per year.

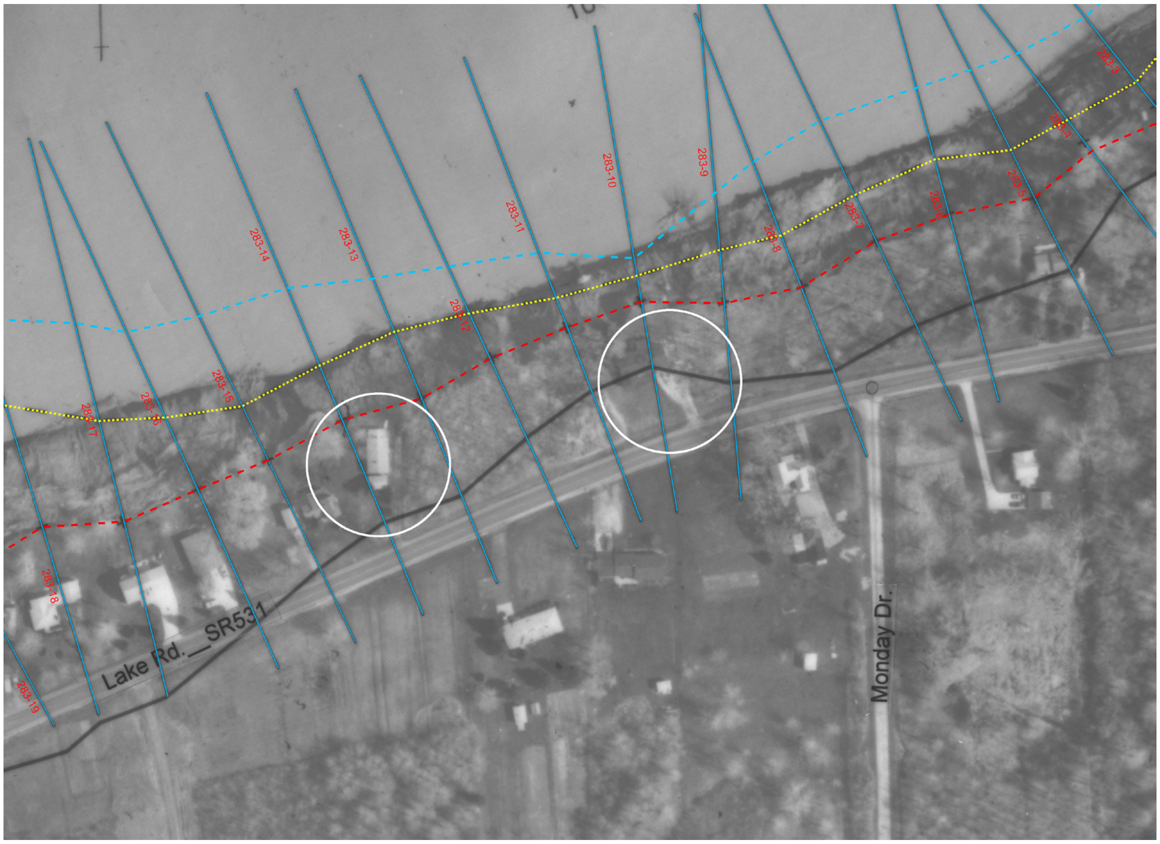


Figure 3A. Properties can be lost to coastal erosion. This 1990 aerial image shows two houses that will be lost to coastal erosion. The blue dashed line indicates the 1876 shoreline; the yellow identifies the 1973 shoreline; and the dashed red line represents the 1990 shoreline. The black line represents the coastal erosion area designation line. The houses are circled in WHITE.

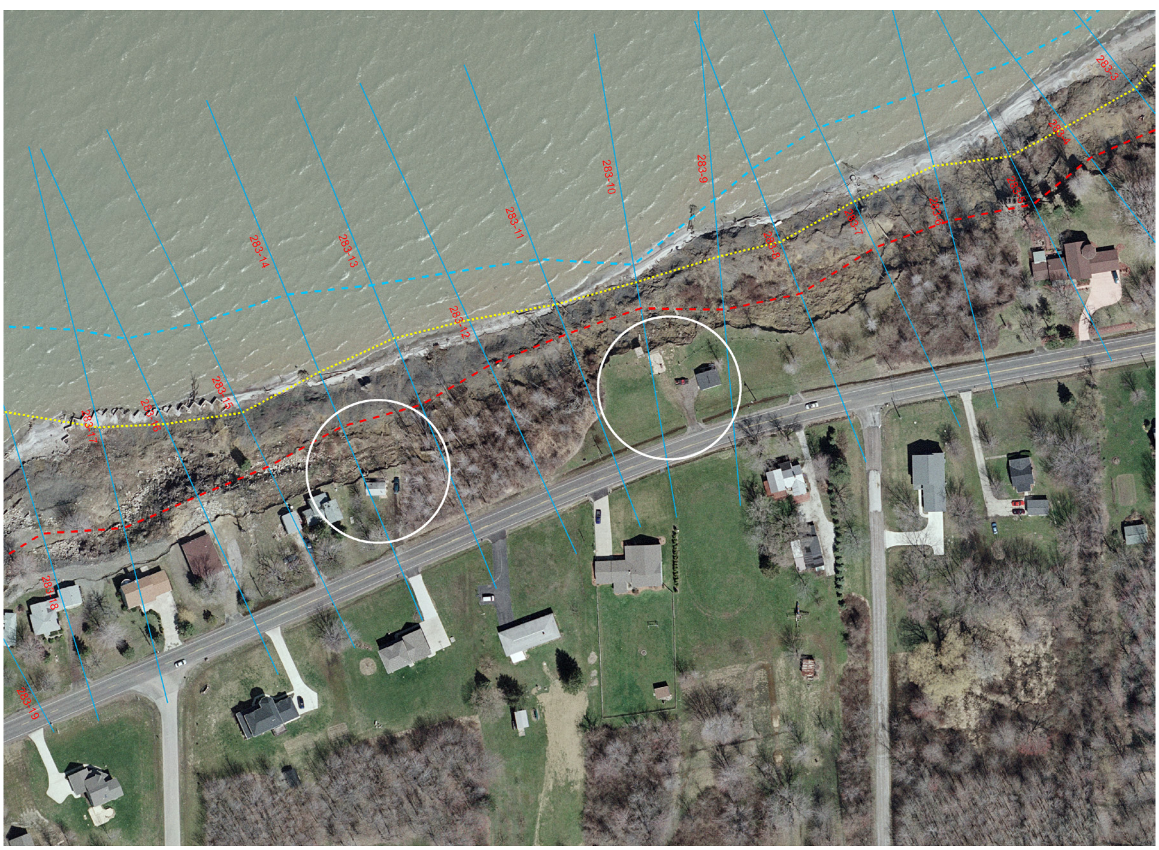


Figure 3B. By 2004, the two houses have been lost to coastal erosion. The location of the former houses are circled in WHITE.

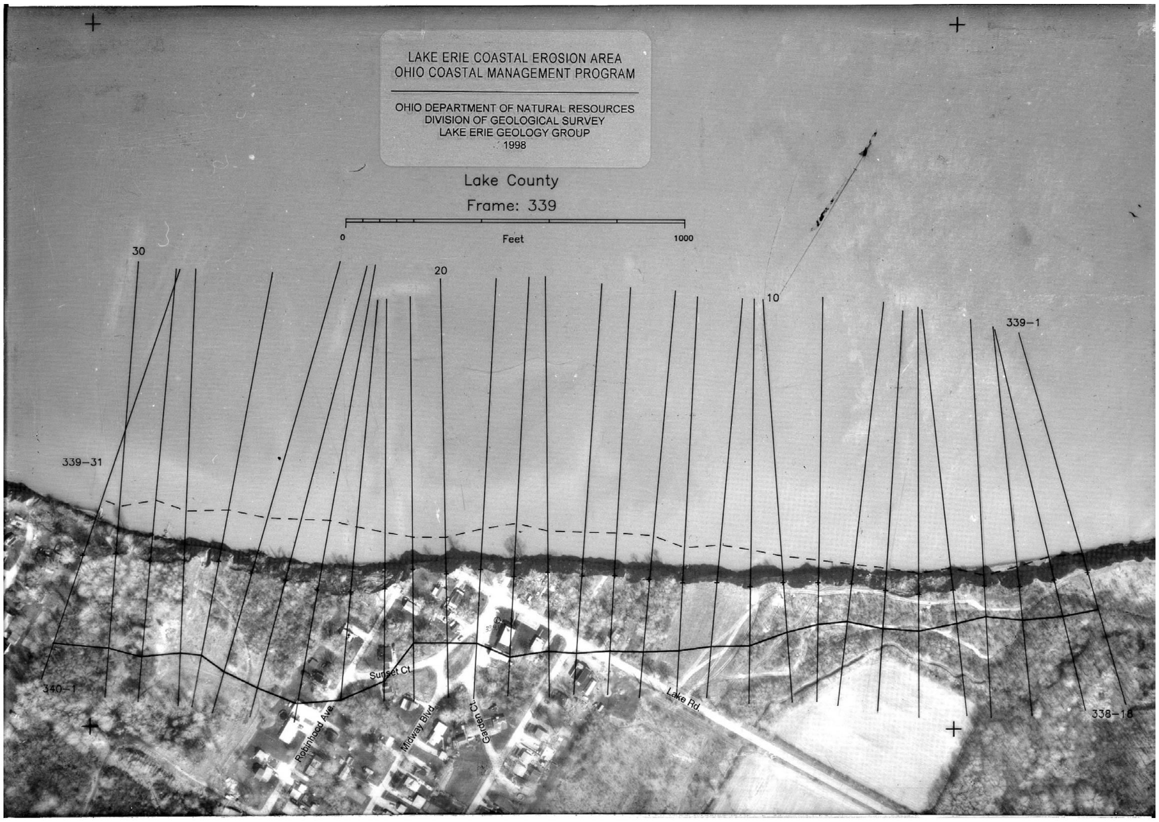


Figure 4. Example of a 1998 coastal erosion area mapbook page for section of Lake Erie coast in Painesville, Ohio.

erosion area delineation using the 1990 and 2004 shorelines. To perform the mandated remapping of coastal erosion areas, the ODNR Division of Geological Survey developed three new GIS applications. First, a GIS application was written that assigns identification numbers to the shore intercepts and shore-normal transects located every 100 feet (or 30 meters) along the Ohio Lake Erie shore. This first GIS application ensures that the identification numbers are unique, contiguous, and have a spatially sequential orientation. Second, a GIS application was written to assist staff members with mapping the 2004 shoreline. This application provided a digitization workflow that significantly reduced the attribute errors associated with digitizing the 2004 shoreline and improved overall quality and precision of the 2004 recession dataset. Third, staff members translated the original FORTRAN 77 code into VBA and ArcObjects for ArcGIS to create an application that automatically calculated the amount and rate of recession and the 30-year average recession distance for each shore-normal transect. These three GIS applications facilitated the task of remapping coastal erosion areas and reduced the time to complete the mapping of the 2004 shoreline from more than 1 year to less than 3 months.

Transect Identification Number Application

Before any work could be performed for the new coastal erosion area delineation, identification numbers had to be assigned to all the shore-normal transects. These Transect Identification numbers (TIDs) are unique, contiguous, and spatially sequenced. The TIDs must be spatially sequenced in order to apply a five-point moving average algorithm used to smooth coastal erosion area lines.

To assign the TIDs, we took advantage of the fact that the 1990 aerial photography was flown in an east-to-west sequence along the coast. Therefore, a sequence number was assigned to each air photo frame. During the 1998 coastal erosion area mapping, shore-normal transects were drawn on each 1990 aerial photo. These transects were uniquely numbered for each aerial photo; the numbers range from 1 to 72, depending in the width of the aerial photo. Using the aerial-photo sequence number and the sequential-transect numbers on each aerial photo, the application iteratively assigns the unique TIDs for the entire coastal dataset (fig. 5). The TIDs range from 1 at the Ohio-Pennsylvania border to 12,157 at the Ohio-Michigan border. The Lake Erie islands TIDs range from 12,158 to 14,164.

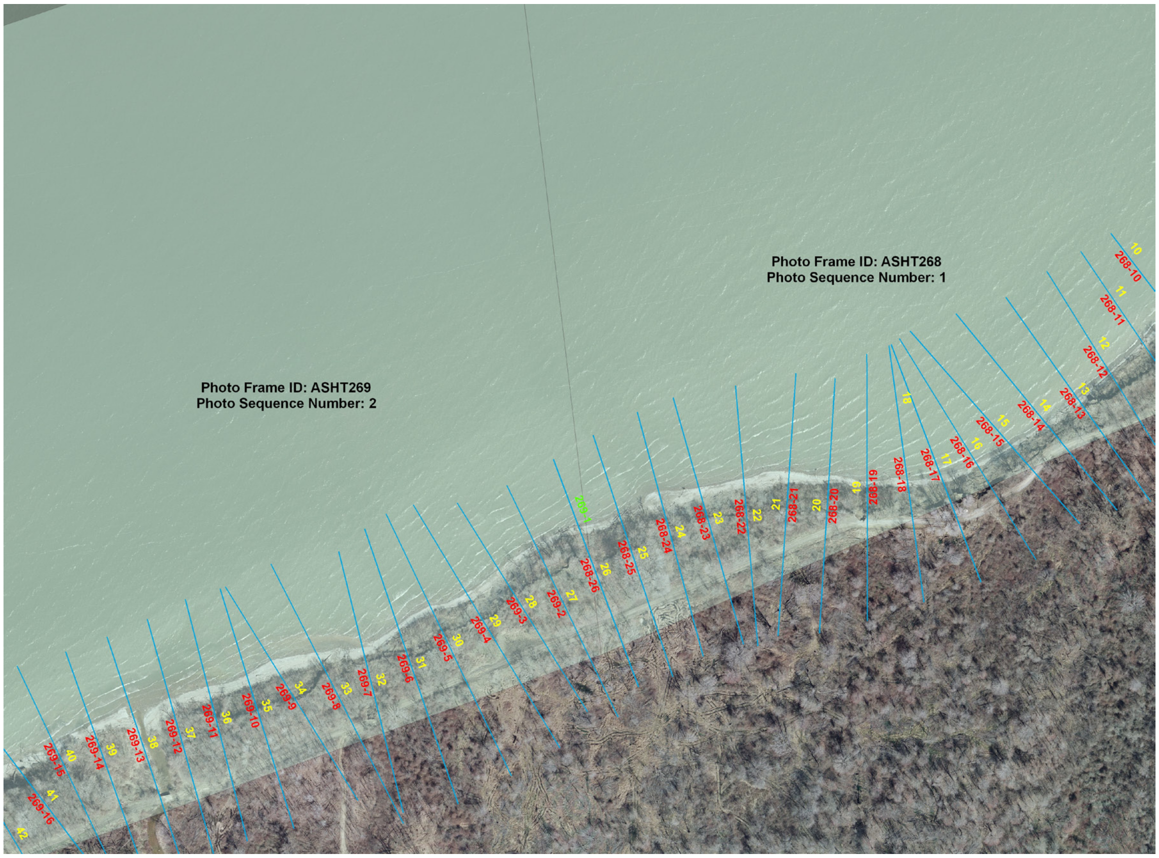


Figure 5. A portion of the Lake Erie coast near the Ohio-Pennsylvania border. The outlines of two 1990 aerial photo frames—frame 268 and frame 269—are shown. Also shown are the aerial-photo sequence numbers. The shore-normal transects (blue lines) are labeled with the original frame and transect identification (TID) numbers (in red). A tie transect (in green, along the boundary between photo frames) is the last transect in a 1990 aerial photo frame and also the first transect in the next frame. The new TIDs are in yellow. The new TID numbers are assigned to the 1870's, 1973, 1990, and 2004 datasets. Aerial photo was taken in 2004.

CEA 2004 Digitizing Application

The CEA 2004 Digitizing Application is a simple, user-friendly application that allows for digitizing the toe of the bluff and the shoreline intersections (fig. 6). Once activated by the user, the application turns on the ArcMap Editor toolbar and sets the snapping tolerance (2 feet) for snapping to the shore-normal transect. The user is then prompted to first digitize the bluff toe (base of the bluff) and then the bluff crest (2004 shore) for each shore-normal transect. The application automatically switches between digitizing the bluff toe and the bluff crest (or other appropriate shore erosion reference feature) for each shore-normal transect. Attributes, such as the TID, the 1990 aerial photo frame number, and the original transect identification number, are automatically copied from the shore-normal transect and written to the newly digitized features in the geodatabase, thereby removing all keyboard entry errors. The application also identifies the user who digitized the feature, along with the date and time the feature was digitized. A user can also assign attributes to the shore-normal transect, including presence or absence of shore protection and an offset to account for anthropogenic erosion (that is, slope grading). By automating the process and significantly reducing keyboard entry errors, the Digitizing Tool application reduced the amount of time for GIS quality-control editing from approximately 160 hours to 8 hours.

CEA Calculator Application

Coastal erosion area calculations are a multistep process (Ohio Department of Natural Resources, 1996). The first step is to calculate the recession distance, which is the distance along the shore-normal transects between the reference shoreline intersection and the older shoreline intersection. Next, the recession rate is calculated by dividing the recession distance by the time interval between the reference shoreline and the most recent shoreline (for example, the 14 years between 1990 and 2004 [fig. 7]). The 30-year recession distance is calculated by multiplying the recession rate by 30 years (see figure 6). The 30-year recession distance is then smoothed using a five-point, center-weighted, moving-average filter (fig. 8). The

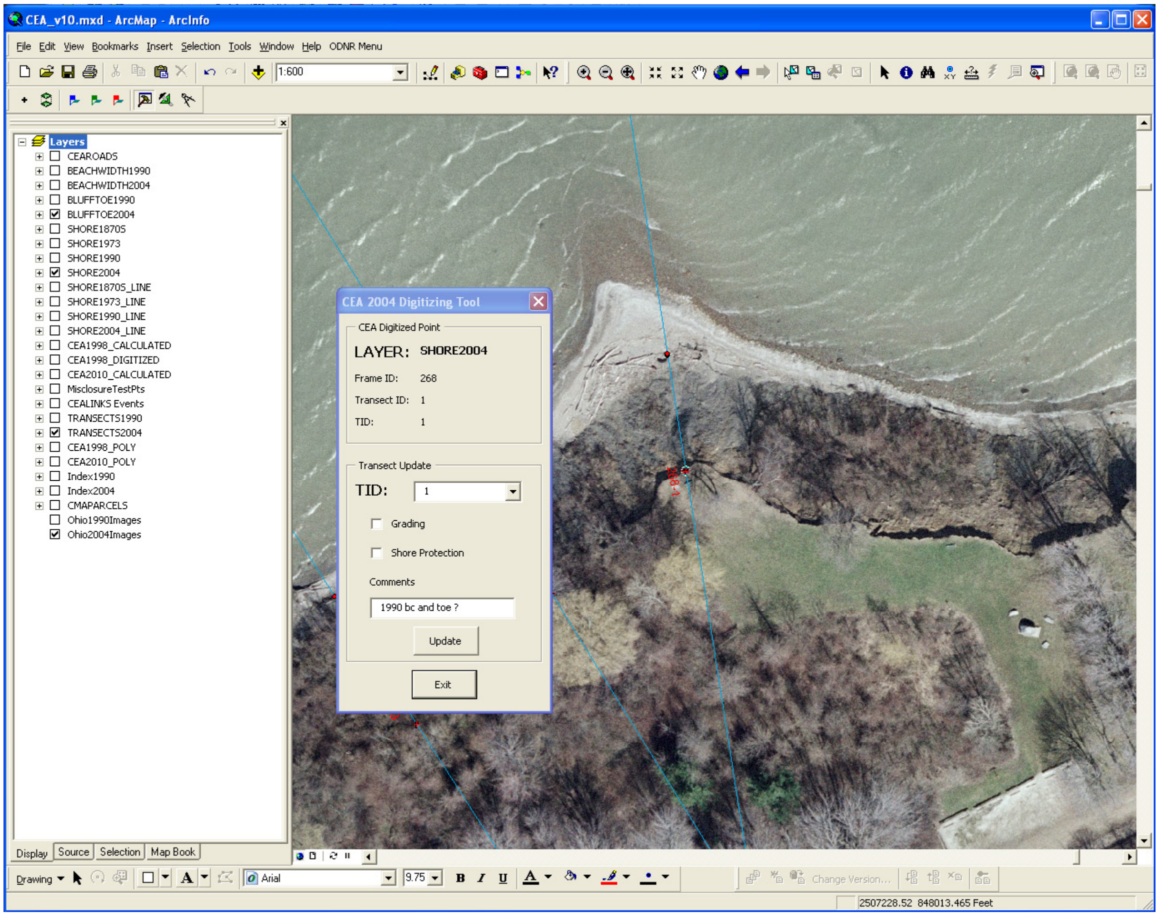


Figure 6. The CEA 2004 Digitizing Application. The VBA form displays the attributes being transferred from transects to the new points. The user has the ability to add attributes as to whether manmade grading has occurred to the bluff slope, whether shore protection has been installed, and other comments about the points which can be included in the dataset.

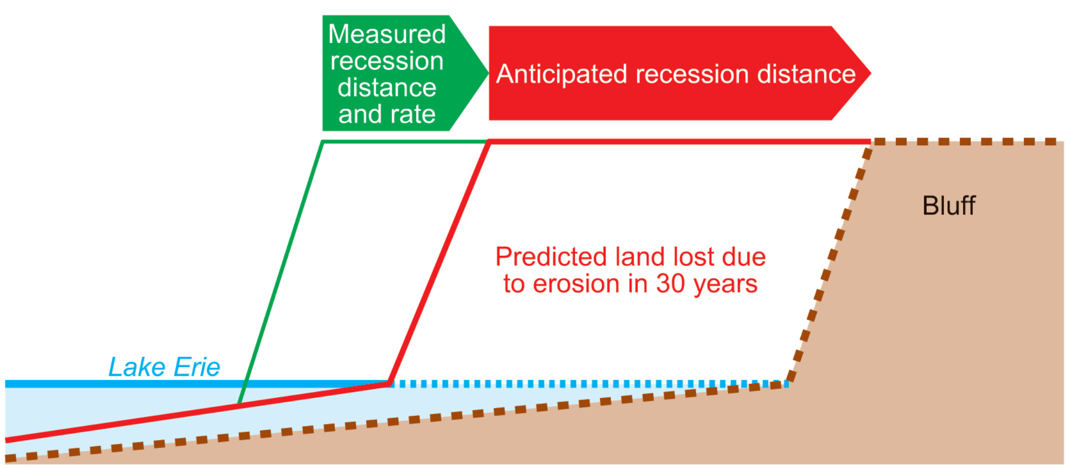


Figure 7. Sample cross section of the Lake Erie bluff showing the measured recession distance (that is, between 1990 and 2004) and the projected 30-year recession distance.

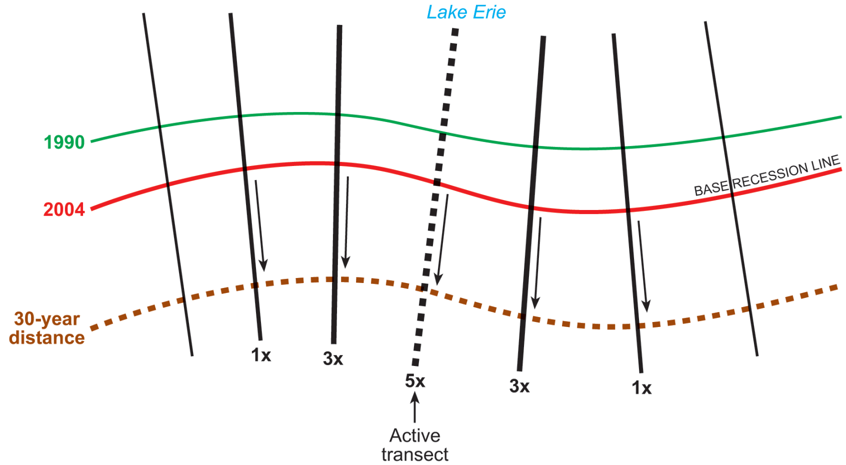


Figure 8. A five-point moving average is used to smooth the projected (30-year) shoreline.

five-point, center-weighted, moving-average filter is required because any small changes in the recession rate are magnified by a factor of 30 and the coastal erosion area designation would be a jagged line. The five-point, center-weighted, moving-average filter is calculated using the 30-year recession distance at a central transect and two transects on either side of the central transect. Weights of 5, 3, and 1 are applied to the five transects. The weighted values are summed and divided by 13 to produce the 30-year average recession (or coastal erosion area) distance at the central transect. The filter then shifts to the next adjacent transect and the process is repeated.

The final step is to plot the coastal erosion area (CEA) designation line (fig. 9). The CEA designation is plotted when the 30-year average recession distance is greater than the Calculated Accuracy Limit (CAL). The CAL value provides a way to incorporate mapping uncertainty into coastal erosion areas. The administrative code (Ohio Department of Natural Resources, 1996) specifies the mapping uncertainty be set at 5 feet total error between the two different mapping epochs. The 5-foot mapping error is divided by the interval in years and then multiplied by 30 to propagate 30 years into the future, creating the CAL. For the first coastal erosion area mapping in 1998, the CAL was computed to be 9 feet. For the upcoming remapping of coastal erosion areas, the CAL is computed to be 11 feet. The CAL acts as a minimum coastal erosion area distance. If the 30-year average recession distance is less than the CAL value, then a coastal erosion area is not designated. If the 30-year average recession distance is greater than the CAL value, then a coastal erosion area is designated.

The CEA Calculator incorporates all of the calculations described above into an easy-to-use application (fig. 10). The application requires four different GIS layers: the reference shoreline and the older shoreline, the toe of the bluff for the most recent year mapped, and the shore-normal transects. For the special case of coastal erosion areas being calculated for a Lake Erie island, a simple checkbox is provided to designate an island calculation.

Coastal erosion area calculations are a three-step process. After selecting all the layers, the operator first creates the CAL line. Then, the operator calculates the recession distance, recession rate, and the 30-year average recession distance. These values are written into the attribute table of the shore-normal transects feature class. Finally, the coastal erosion area designation lines are plotted using the application. These three operations are performed using a simple selection of the three command buttons.

The CEA Calculator application was originally written in FORTRAN 77 for the 1998 coastal erosion area mapping project. For the latest remapping, the application was converted to VBA using ArcObjects. Since coastal erosion area designation is a regulatory program, the ODNR Division of

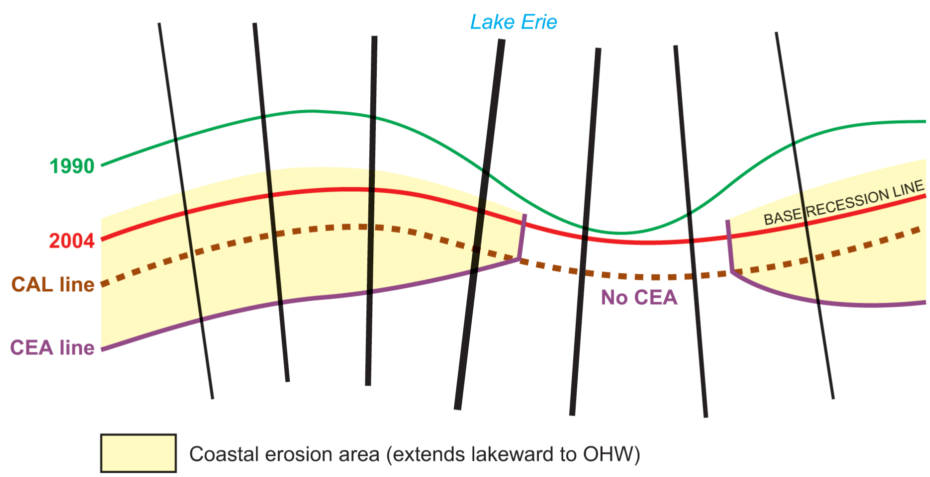


Figure 9. All the components either used or calculated during the Lake Erie coastal erosion area designation are shown here. The 1990 shoreline/bluff crest (green line) and 2004 shoreline (red line) are mapped using aerial photography. The black lines perpendicular to the shore are the shore-normal transects, which are used as reference lines for measuring shore recession. The Calculated Accuracy Limit (CAL; dashed, brown line) is created using the 2004 shoreline/bluff crest as the base recession line. Finally, coastal erosion area (CEA) lines (purple line) are calculated and plotted back into the GIS database using the CAL line and annual-recession distance projected 30 years into the future. The coastal erosion area (yellow shaded area) extends lakeward from the CEA line to the ordinary high-water (OHW) mark on the lake.

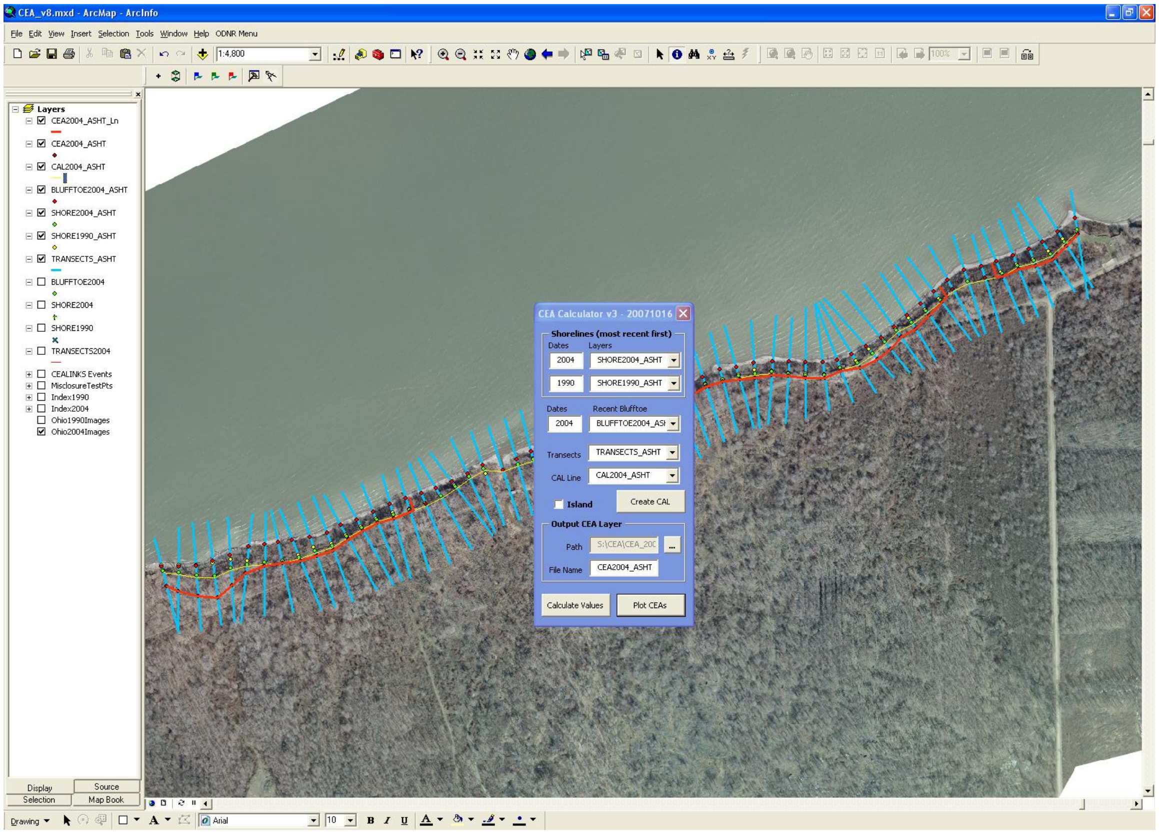


Figure 10. The CEA Calculator application.

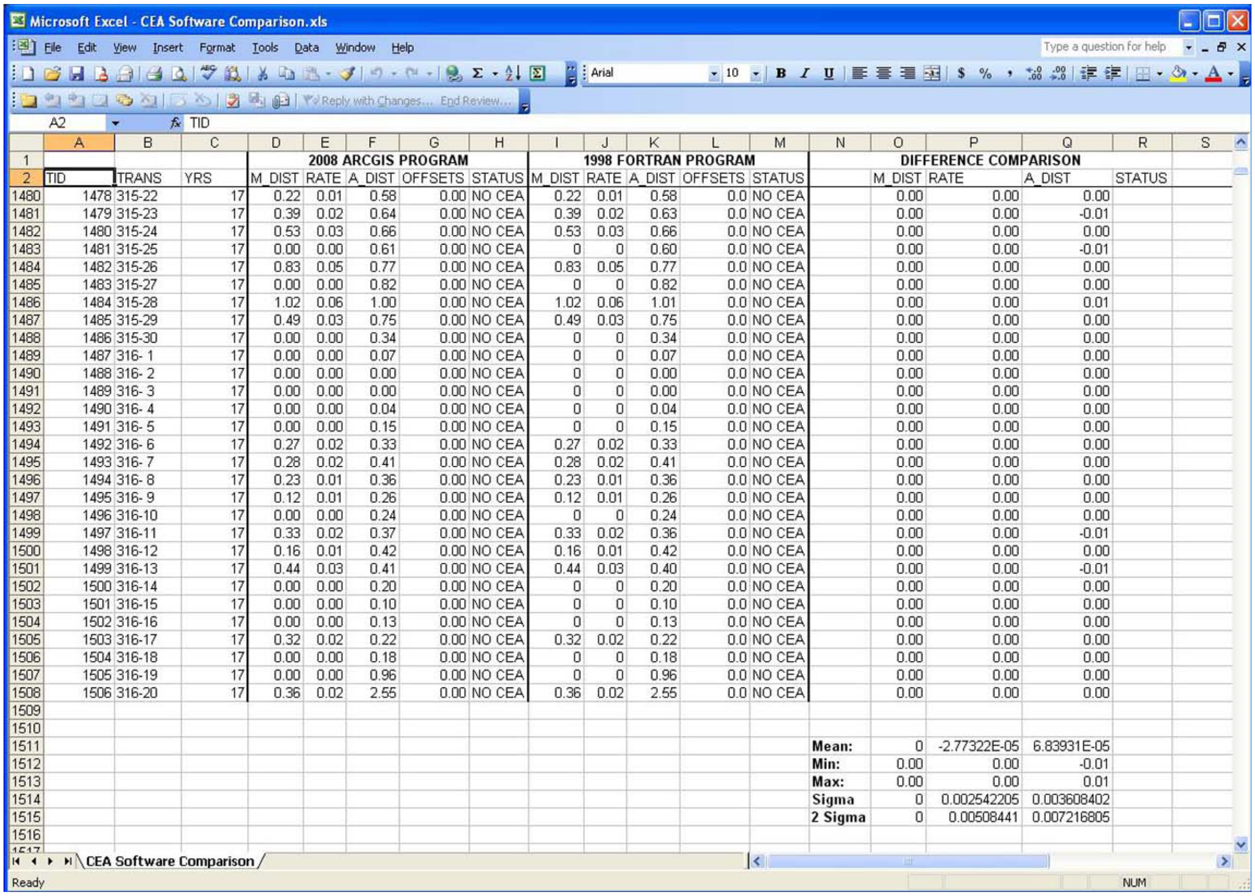
Geological Survey had to ensure that the output from the VBA using ArcObjects code exactly reproduced the output from the FORTRAN 77 code by comparing the output from the two applications (fig. 11). The 30-year average recession distances compare to within 0.01 feet. These results assure us that we correctly translated the application code from FORTRAN 77 to VBA using ArcObjects.

Conclusions

Three GIS applications were developed to assist the ODNR Division of Geological Survey to map coastal erosion areas along the Ohio Lake Erie Shore, which resulted in significant time and cost savings to the coastal erosion area mapping project. The TID application assigned unique identification numbers to all the features in the coastal erosion area GIS. Over 166,000 features have TIDs assigned. We used the 2004 Digitizing Application to map shore features that were used to calculate recession distances, which significantly reduced keyboard entry errors. Digitizing the 2004 shoreline took approximately 3 months to complete using this application, while the previous coastal erosion area mapping took approximately 1 year to complete. The CEA Calculator tool was successfully converted from FORTRAN 77 to VBA using ArcObjects and then applied to the 2004 dataset to calculate new coastal erosion areas and to identify coastal properties at risk to Lake Erie-related coastal erosion.

Now that the preliminary mapping is complete, additional products can be developed with the new GIS data. Traditional products created for the 1998 coastal erosion area mapping project included map books (fig. 12) and data table books. Similar products can be easily produced using the 2004 GIS dataset. The public is already familiar with these products, and these products can be rapidly generated and updated with ease. The maps will be made public via a Web map application on the ODNR Web site, and hard copies will be made available at select repositories and public buildings along the coast.

The new coastal erosion area GIS data can be combined with other geospatial datasets. For example, the coastal erosion area GIS dataset can be overlaid with county auditors' parcel owner data, and those parcels affected by coastal erosion area designations can be easily identified. In addition, those parcel owners that are dropped from the 1998 coastal erosion area designation can be easily identified. By performing these overlay operations in the GIS environment, we can rapidly identify the property owners who are affected by the new coastal erosion area designation, along with those property owners who were originally in the 1998 coastal erosion areas and are being dropped from the new designation. Affected property owners can then be notified.



Microsoft Excel - CEA Software Comparison.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1				2008 ARCGIS PROGRAM					1998 FORTRAN PROGRAM						DIFFERENCE COMPARISON				
2	TID	TRANS	YRS	M_DIST	RATE	A_DIST	OFFSETS	STATUS	M_DIST	RATE	A_DIST	OFFSETS	STATUS		M_DIST	RATE	A_DIST	STATUS	
1480	1478	315-22	17	0.22	0.01	0.58	0.00	NO CEA	0.22	0.01	0.58	0.0	NO CEA		0.00	0.00	0.00		
1481	1479	315-23	17	0.39	0.02	0.64	0.00	NO CEA	0.39	0.02	0.63	0.0	NO CEA		0.00	0.00	-0.01		
1482	1480	315-24	17	0.53	0.03	0.66	0.00	NO CEA	0.53	0.03	0.66	0.0	NO CEA		0.00	0.00	0.00		
1483	1481	315-25	17	0.00	0.00	0.61	0.00	NO CEA	0	0	0.60	0.0	NO CEA		0.00	0.00	-0.01		
1484	1482	315-26	17	0.83	0.05	0.77	0.00	NO CEA	0.83	0.05	0.77	0.0	NO CEA		0.00	0.00	0.00		
1485	1483	315-27	17	0.00	0.00	0.82	0.00	NO CEA	0	0	0.82	0.0	NO CEA		0.00	0.00	0.00		
1486	1484	315-28	17	1.02	0.06	1.00	0.00	NO CEA	1.02	0.06	1.01	0.0	NO CEA		0.00	0.00	0.01		
1487	1485	315-29	17	0.49	0.03	0.75	0.00	NO CEA	0.49	0.03	0.75	0.0	NO CEA		0.00	0.00	0.00		
1488	1486	315-30	17	0.00	0.00	0.34	0.00	NO CEA	0	0	0.34	0.0	NO CEA		0.00	0.00	0.00		
1489	1487	316- 1	17	0.00	0.00	0.07	0.00	NO CEA	0	0	0.07	0.0	NO CEA		0.00	0.00	0.00		
1490	1488	316- 2	17	0.00	0.00	0.00	0.00	NO CEA	0	0	0.00	0.0	NO CEA		0.00	0.00	0.00		
1491	1489	316- 3	17	0.00	0.00	0.00	0.00	NO CEA	0	0	0.00	0.0	NO CEA		0.00	0.00	0.00		
1492	1490	316- 4	17	0.00	0.00	0.04	0.00	NO CEA	0	0	0.04	0.0	NO CEA		0.00	0.00	0.00		
1493	1491	316- 5	17	0.00	0.00	0.15	0.00	NO CEA	0	0	0.15	0.0	NO CEA		0.00	0.00	0.00		
1494	1492	316- 6	17	0.27	0.02	0.33	0.00	NO CEA	0.27	0.02	0.33	0.0	NO CEA		0.00	0.00	0.00		
1495	1493	316- 7	17	0.28	0.02	0.41	0.00	NO CEA	0.28	0.02	0.41	0.0	NO CEA		0.00	0.00	0.00		
1496	1494	316- 8	17	0.23	0.01	0.36	0.00	NO CEA	0.23	0.01	0.36	0.0	NO CEA		0.00	0.00	0.00		
1497	1495	316- 9	17	0.12	0.01	0.26	0.00	NO CEA	0.12	0.01	0.26	0.0	NO CEA		0.00	0.00	0.00		
1498	1496	316-10	17	0.00	0.00	0.24	0.00	NO CEA	0	0	0.24	0.0	NO CEA		0.00	0.00	0.00		
1499	1497	316-11	17	0.33	0.02	0.37	0.00	NO CEA	0.33	0.02	0.36	0.0	NO CEA		0.00	0.00	-0.01		
1500	1498	316-12	17	0.16	0.01	0.42	0.00	NO CEA	0.16	0.01	0.42	0.0	NO CEA		0.00	0.00	0.00		
1501	1499	316-13	17	0.44	0.03	0.41	0.00	NO CEA	0.44	0.03	0.40	0.0	NO CEA		0.00	0.00	-0.01		
1502	1500	316-14	17	0.00	0.00	0.20	0.00	NO CEA	0	0	0.20	0.0	NO CEA		0.00	0.00	0.00		
1503	1501	316-15	17	0.00	0.00	0.10	0.00	NO CEA	0	0	0.10	0.0	NO CEA		0.00	0.00	0.00		
1504	1502	316-16	17	0.00	0.00	0.13	0.00	NO CEA	0	0	0.13	0.0	NO CEA		0.00	0.00	0.00		
1505	1503	316-17	17	0.32	0.02	0.22	0.00	NO CEA	0.32	0.02	0.22	0.0	NO CEA		0.00	0.00	0.00		
1506	1504	316-18	17	0.00	0.00	0.18	0.00	NO CEA	0	0	0.18	0.0	NO CEA		0.00	0.00	0.00		
1507	1505	316-19	17	0.00	0.00	0.96	0.00	NO CEA	0	0	0.96	0.0	NO CEA		0.00	0.00	0.00		
1508	1506	316-20	17	0.36	0.02	2.55	0.00	NO CEA	0.36	0.02	2.55	0.0	NO CEA		0.00	0.00	0.00		
1509																			
1510																			
1511														Mean:	0	-2.77322E-05	6.83931E-05		
1512														Min:	0.00	0.00	-0.01		
1513														Max:	0.00	0.00	0.01		
1514														Sigma	0	0.002542205	0.003608402		
1515														2 Sigma	0	0.00508441	0.007216805		
1516																			

CEA Software Comparison

Figure 11. Portion of a table showing the comparison of the recession distance, recession rate, and 30-year average recession distance generated by both the original FORTRAN 77 coastal erosion area code and the new VBA and ArcObjects coastal erosion area code.

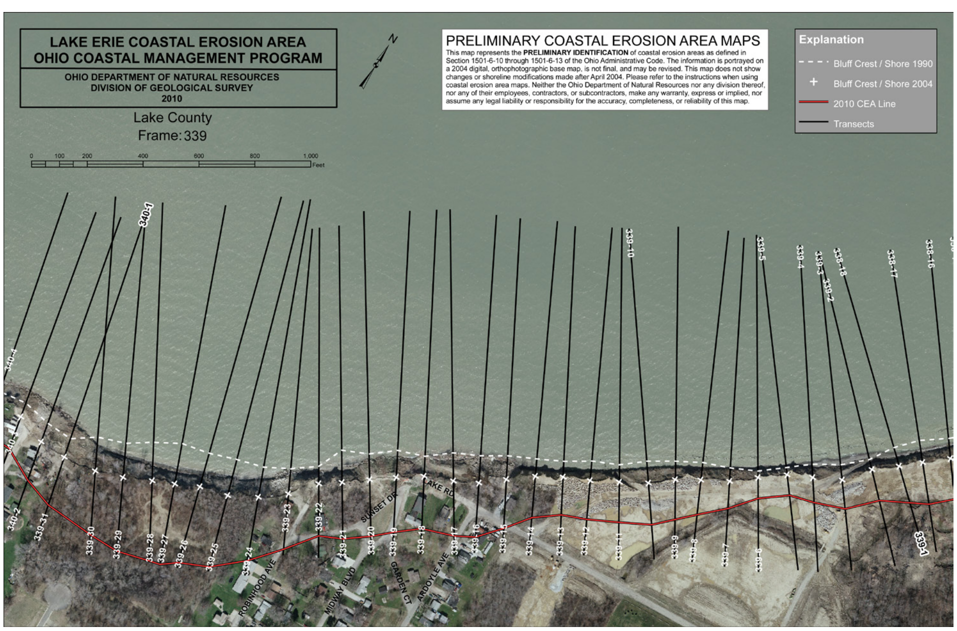


Figure 12. Example map book page (for a section of Lake Erie coast in Painesville, Ohio) from the coastal erosion area GIS dataset.

The coastal erosion area GIS dataset also can be combined with other datasets to perform scientific investigations. The ODNR Division of Geological Survey has created a shore structure inventory along the Lake Erie coast of Ohio (Fuller and Gerke, 2005). The combination of the shore structure inventory, the 1998 coastal erosion area results, and the newly available coastal erosion area designation can be used to evaluate the relative effectiveness of shore structures in reducing coastal erosion rates.

Acknowledgments

We would like to thank staff members Bruce Gerke, Connie Livchak, and Sherry Lingle and Habitat Solutions NA contractor Dale Liebenthal for their assistance in completing the 2004 mapping portion of the project.

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Minnesota Geological Survey Information Systems

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Abstract

Although much information on geological observations, measurements, and inferences is held by the private sector, public geological survey agencies have been charged with maintaining systematic, regional, and jurisdiction-wide information that is meant to clarify the context of site investigations, and to support the progress of research and regional planning. This information includes reports and maps that convey interpretations, and geophysical, geochemical, and geological databases that provide observations and measurements, as well as needed collections of tangible materials such as rock samples and thin sections.

In coordination with the Federal role of the U.S. Geological Survey, and international geological survey initiatives, current emphasis at the Minnesota Geological Survey (MGS) is on systematic enhancement of digital information on the statewide scale, while also focusing on county-scale needs. Particular emphasis has been placed on accelerated production of multi-layered, 1:100,000 County Geologic Atlases, complete with associated databases, that are needed for regional management of groundwater resources. In addition, statewide geological mapping compilations are being developed at scales of 1:100,000 and 1:500,000, implementing current digital methods that allow content to be zoomed, queried, and viewed in 3D.

While publication sales, the Web site (*http://www.geo.umn.edu/mgs/*), and ftp capability are being maintained, current intentions are to shift information products to Open Geospatial Consortium-compliant Web Services. This will allow users either to gain access to MGS products through the conventional MGS Web site or to gain direct access to the data through their preferred GIS platform or Web interface.

Introduction

The Minnesota Geological Survey (MGS) was established in 1872 by the State of Minnesota as part of the University of Minnesota to serve the needs of the people of Minnesota for systematic geoscience surveys required to ensure their prosperity, health, and security through stewardship of water, land, and mineral resources. The format of this mapping and monitoring has evolved with the progress of science and technology. Its use has been optimized through accompanying research and outreach, and MGS works closely with university, government, industry, and community partners to ensure that these ongoing geological, geophysical, and geochemical surveys respond to the evolving needs of societal applications.

Under this mandate, MGS has assembled systematic information and reference materials related to Minnesota geology, not only through its own surveys, but also through cooperation with the U.S. Geological Survey (USGS), and through compilation of information and materials derived from water well drilling, State agency resource and health regulatory activity, university research, mineral exploration, and engineering-related activity.

Reference materials and data resulting from these activities are held at MGS offices in Saint Paul. In addition, MGS contributes to the drill core library and the mineral exploration document archive managed by the Minnesota Department of Natural Resources (DNR) in the town of Hibbing, MN. MGS also contributes to the principal Minnesota paleontological archive, housed on the University of Minnesota Twin Cities campus and managed by the University of Minnesota Department of Geology and Geophysics.

This paper reviews the status of MGS publications, collections, databases, and new geological mapping products, as well as plans for the evolution of these products and their delivery.

Publications

Production of a publication, with specified authorship and series number, has been the conventional way to formally produce information that meets the standards set by the institution, under the direction of the Chief Geologist, and with the authorization of the Director. MGS publications have been released in 25 printed series, such as aeromagnetic maps, annual reports, bulletins, county geologic atlases, guidebooks, information circulars, miscellaneous maps, and reports of investigations.

Unlike the past paradigm, in which users were referred to libraries and used book dealers in the case of out-of-print publications, MGS is now making a commitment to ensuring the indefinite availability of all of its publications, by completely scanning and linking to the MGS Web site all new and older MGS publications. An exception is the open file series, whose status with respect to indefinite availability remains to be clarified, due to possibly incomplete cataloging and archiving.

Although databases are intended to meet scientific standards in a manner comparable to publications, these databases operate according to protocols distinct from those of publications. For example, the incremental growth of some databases, sometimes on a daily basis, and database maintenance are not usual requirements of standard publications. In addition, MGS from time to time produces contract deliverables, and if no series number is assigned to those products, no commitment is made to the long-term availability of the item.

Catalog and Collections

The MGS publications database will progressively be enhanced as indexing practices evolve. The hard-copy collections of every publication with a series number released by MGS since inception of the agency in 1872, other than open files, have been updated at the Minnesota Geological Survey Library, at the University of Minnesota Library, and in University of Minnesota archives. MGS will ensure the ongoing availability of this database to, for example, the National Geologic Map Database.

Searchable Page Scans

Since 1872, the MGS has published over 40,000 pages of reports. With support from University of Minnesota Libraries, Digital Collections Unit, these have now been scanned by a contractor (fig. 1). Files in PDF format with searchable optical character recognition (OCR) content have been created, and are now linked from the MGS Web site. We also plan for the scans to become digital books that can be quickly searched and viewed on the Web on a single-page basis, rather than time-consuming whole-file download, as soon as format evolution stabilizes. Bound foldouts in the original publications will be part of the PDF files and digital books, whereas folded inserts will be available as separate images in the scanned map collection.

Figure 1. The 40,000 pages of reports MGS has published, which fit in six boxes, were scanned by a contractor in two batches.

Web Accessible Map Images

MGS has published over 600 maps in its history. These were scanned as one batch with support from University of Minnesota Libraries, Digital Collections Unit. Raster files are now linked from the Web site, and PDF files are available for download (fig. 2). There will be an ongoing effort to optimize searchable OCR content in these files. Folded inserts from reports are included among these maps.

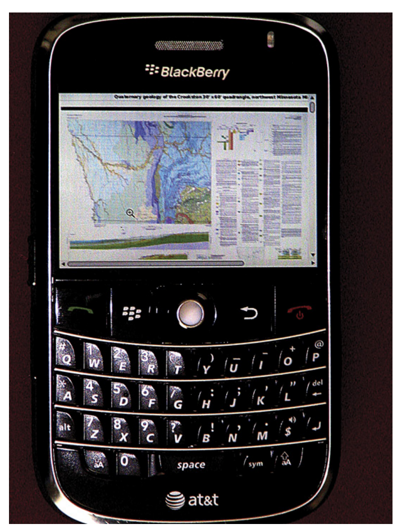

Figure 2. The 600 maps MGS has published were scanned in one batch and are Web accessible as rasters.

Collections

MGS collections include field notebooks, hand samples, thin sections, sediment samples, geochemical samples, and cuttings (fig. 3). Each collection is accompanied by a database of metadata, such as sample identification, field location, and storage location. Concurrently, DNR administers the drill core library (fig. 4) and mineral exploration file archive, and the university holds the paleontological archive; both collections are well cataloged and stored. MGS presently is working with support from the USGS Data Preservation program to improve cataloging of its collections. Ideally, every item would be cataloged and georeferenced, such that it is mappable and findable. The hand samples are, however, only cataloged at the collection, rather than item, level. In the case of both hand samples and thin sections, much of the location information remains at the project rather than the item level. Long-term plans call for gradual improvement of item-level cataloging and georeferencing of the collections.

Databases

MGS databases include field observations, karst database, sediment textural and lithological data, geochemical database, aeromagnetic database, gravity database, rock properties database, borehole geophysical logs, the County Well Index water well database (figs. 5 to 8) that MGS co-manages with the Minnesota Department of Health (MDH), and geotechnical data. Materials and data are well stored, although document

Figure 3. MGS hand samples have been cataloged at the project, but not yet at the item, level.

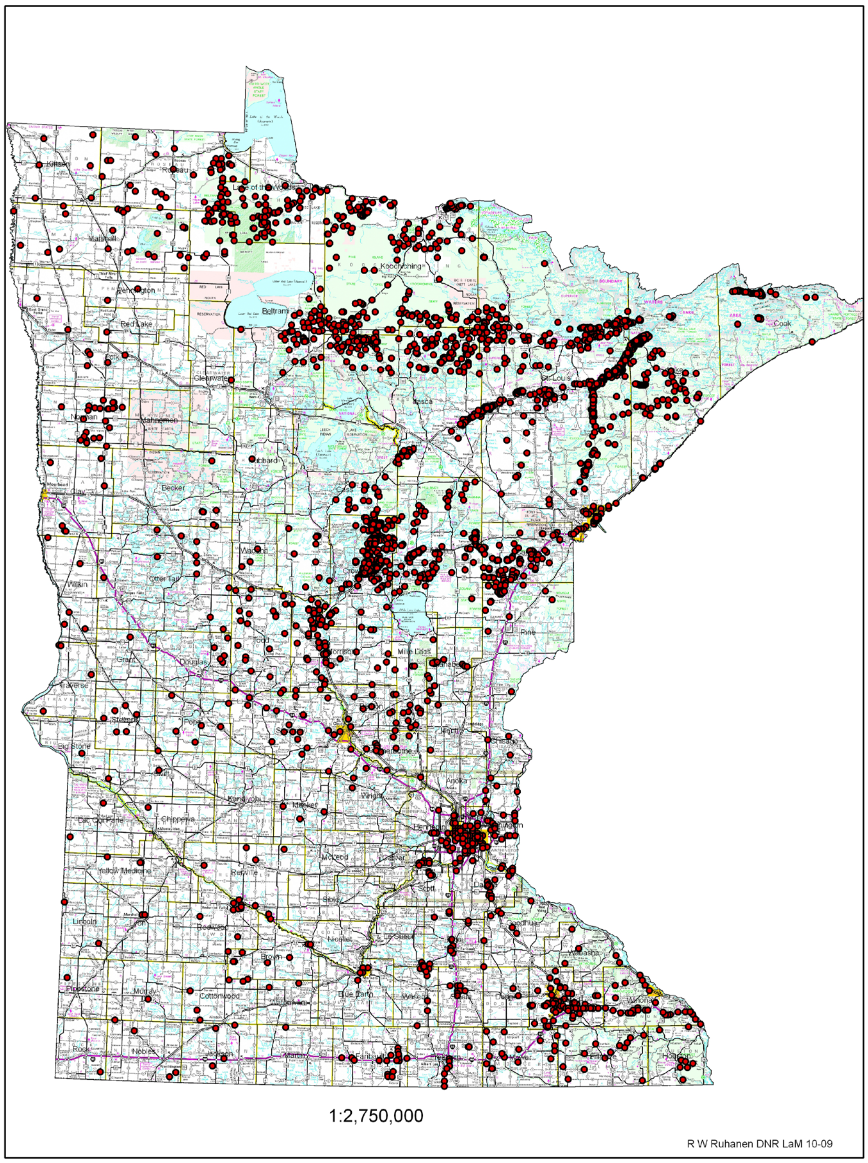

Figure 4. The DNR drill core library holds core from sites across the State; figure derived from the library catalog.

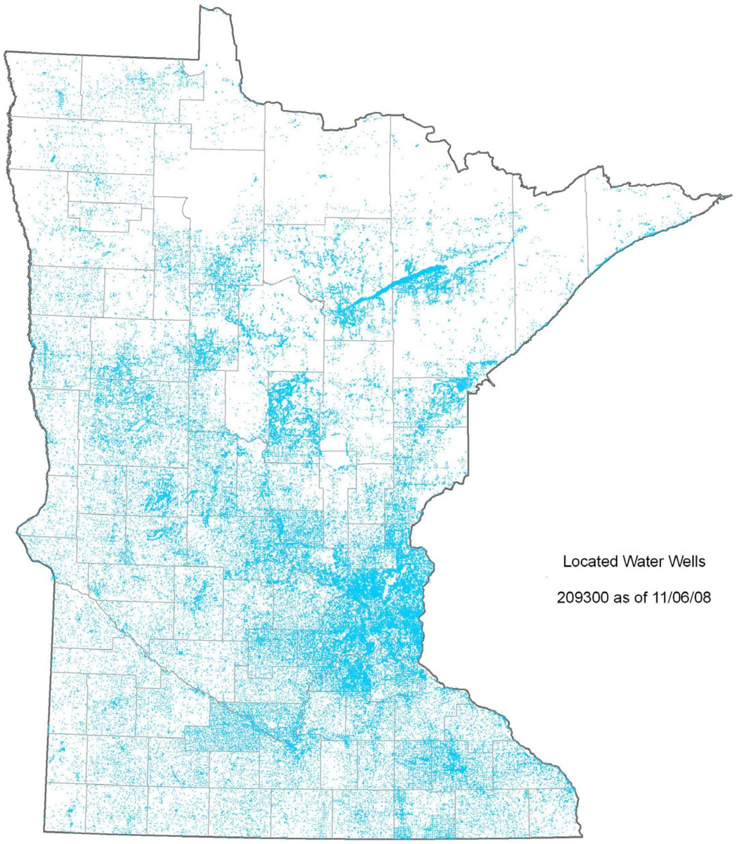

Figure 5. Distribution of located sites in the Minnesota drillhole database; figure derived from the database.

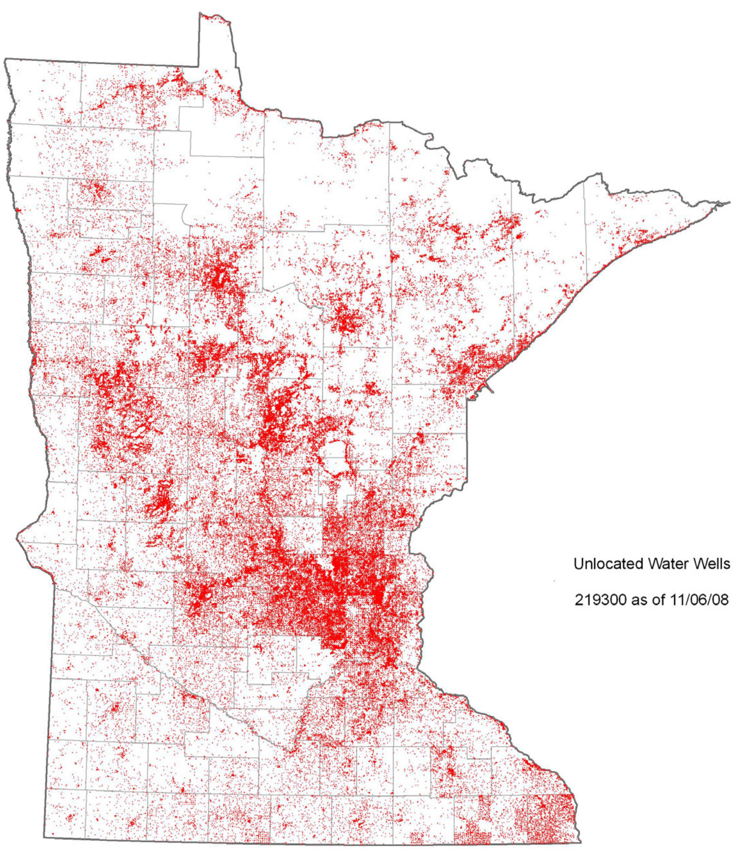

Figure 6. Distribution of sites in the Minnesota drillhole database located to legal survey polygon only; figure derived from the database.

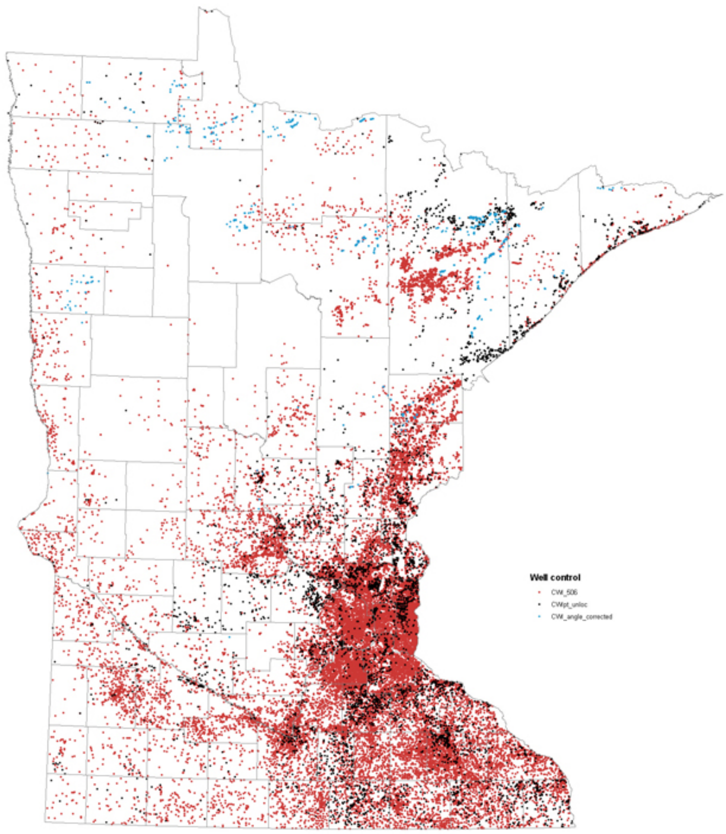

Figure 7. Distribution of drillholes that intersect bedrock, including located, unlocated, and inclined holes; figure derived from the database.

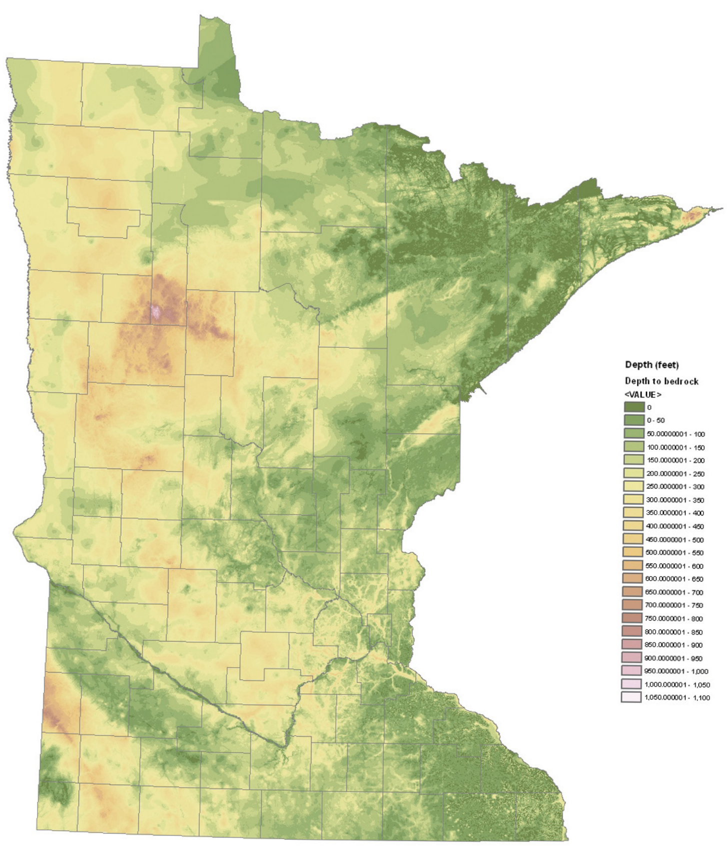

Figure 8. Map of bedrock topography produced from bedrock intersections in the Minnesota drillhole database; from MGS working files.

collections associated with partially digitized content are vulnerable to damage from various natural disasters. Priority for improvements has been placed on the most pressing database content enhancements, more consistent and interoperable database structures, and improved Web accessibility.

Enhancements to Geophysical Databases

In 2007, the Minnesota aeromagnetic database was reprocessed to recover line data missing from the original digital archive, to mitigate line-leveling errors that locally caused striping artifacts, and to use the revised data to produce a higher resolution aeromagnetic grid for the entire State, resulting in a much-enhanced ability to resolve features (fig. 9). In the months ahead, the 58,000-site gravity database will similarly be improved by enhancing station location precision (fig. 10). In addition, the rock property database that provides density, magnetic susceptibility, and other data that are used to link geophysical properties to geological mapping will be updated with elevations and downhole information where available.

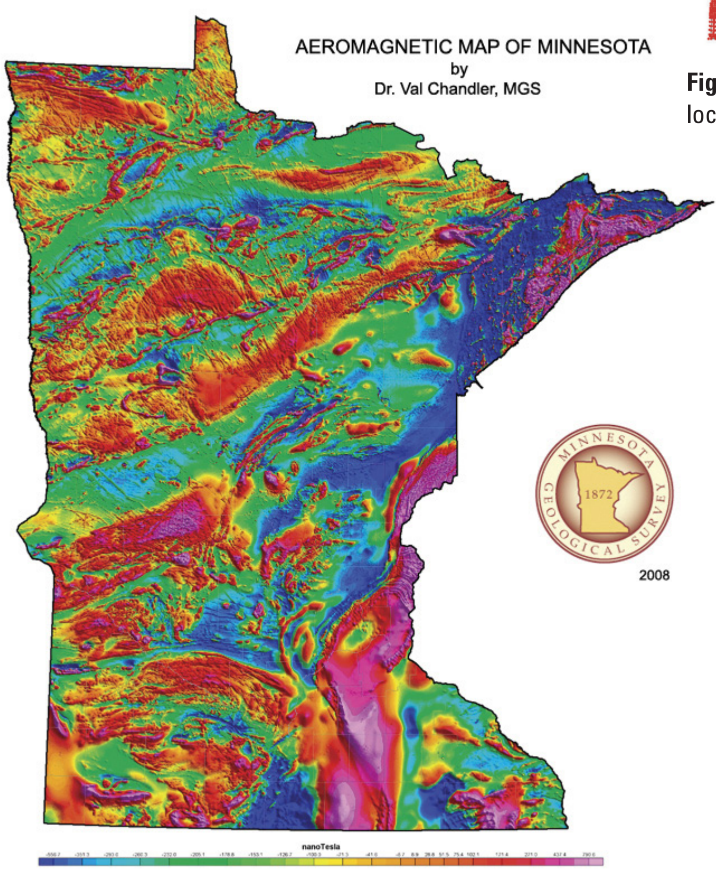

Figure 9. Greatly enhanced feature resolution has been obtained by fully reprocessing the magnetic database (*http://www.geo.umn.edu/mgs/magnetics.htm*).

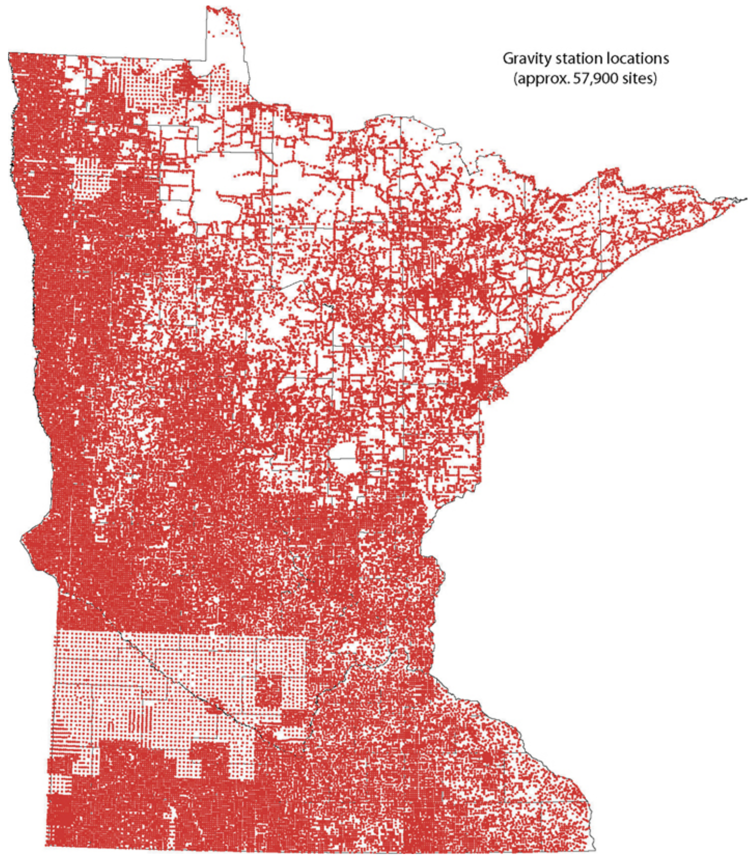

Figure 10. The gravity database will be enhanced by improving site location precision (*http://www.geo.umn.edu/mgs/gravity.htm*).

Geochemical Database

The need for documented statewide geochemical information is escalating as exploration geochemical surveys need reference data to provide regional context, because project permitting requires documentation of current conditions, and cleanup efforts require information about existing background levels of contaminants. MGS therefore worked with the USGS and the Minnesota Pollution Control Agency between 2007 and 2009 to assemble and map statewide geochemical data for soil, soil parent material, and groundwater in selected aquifers. Resulting documentation, maps, a poster, and databases are now online (fig. 11, *http://www.geo.umn.edu/mgs/geochem_rpt/geochem_rpt.htm*).

Compilation of Hydrogeological Properties

Regional hydrogeological characterization of groundwater systems is an ongoing high priority activity for MGS. Increased effort therefore is being directed at quantifying hydrogeological characteristics, initially focusing on the most heavily used carbonate and sandstone aquifers in southeastern Minnesota (Runkel and others, 2003). Based on compilation and interpretation

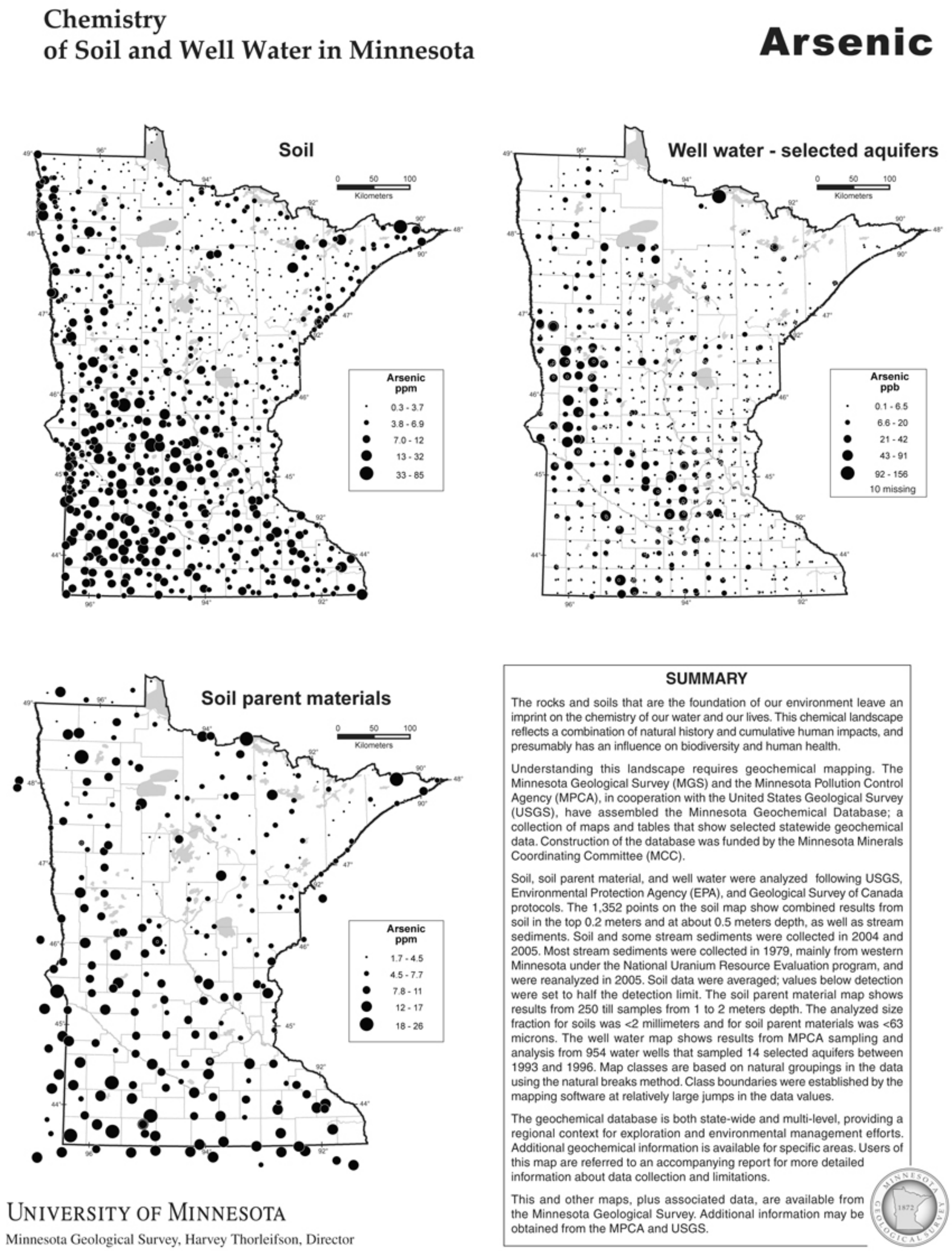

Figure 11. A geochemical atlas has been produced to depict soil, till, and groundwater geochemical data (*http://www.geo.umn.edu/mgs/geochem_rpt/geochem_rpt.htm*)

of a large amount of hydrostratigraphic and hydraulic data, a hydrogeological framework is being developed that is influencing groundwater management strategies and improving the ability to predict aquifer productivity and contaminant transport by providing improved definition and characterization of groundwater systems. Plans call for this activity to eventually be broadened to the statewide scale, and for groundwater systems hosted by Quaternary strata to be better characterized (fig. 12).

New Geological Mapping Products

Geological maps were devised nearly two centuries ago, and since that time, they have had a consistent format designed to accommodate the constraints of the printing press. We remain committed to this format, as it is a standard that we know well and that will certainly be usable a century from now. Geological mapping is, however, undergoing rapid

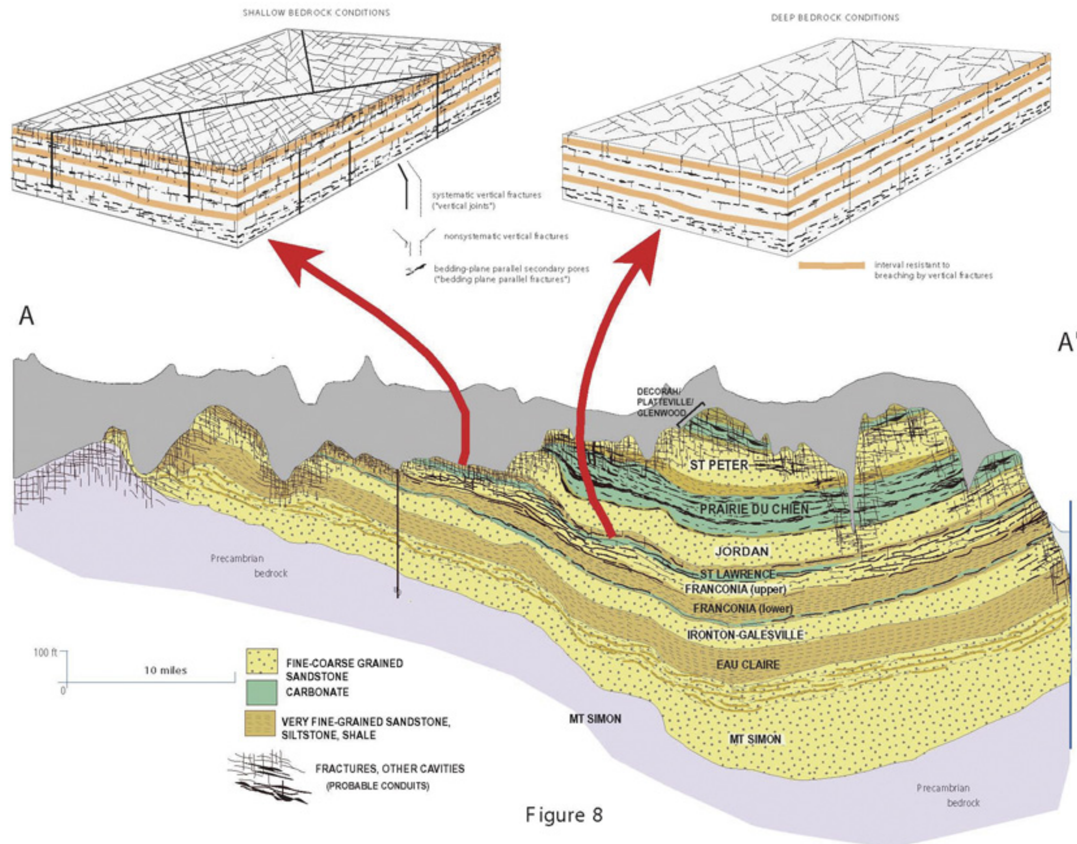

Figure 12. Graphic depiction of hydrogeological properties; increased compilation of hydrogeological measurements is being considered (from Runkel and others, 2003).

evolution due to the availability of digital technology, accelerating computing capacity, and increasing levels of data input. During the 1990s, digital cartography was adopted, and we learned how to make a paper map with a computer. For at least two decades, the format of geological map products has been evolving beyond the constraints of the printing press. Users of GIS and Web mapping systems are accustomed to maps being zoomable and queryable. MGS, like other surveys, therefore is developing new map products that in many ways will serve as the foundation for a broad range of future outputs such as maps, databases, and 3D visualizations on the Web. Although questions about the format and distribution of these products remain to be clarified, the trend is clear.

New Multi-Layered State Geological Map

Having completed a considerable amount of new geological mapping since the last statewide bedrock geological map was published in 2000, and having reprocessed the aeromagnetic data, a new 1:500,000 State Bedrock Geological Map is now being produced. In GIS format, the map will have separate layers for water, Quaternary, Mesozoic, Paleozoic, and late Precambrian rocks (figs. 13 to 16). These layers will be removable, allowing the user to see the geology that lies beneath. Archean and other basement rocks will comprise the basal layer of the rock GIS themes. Additional themes will include diabase dikes and metamorphic grade, bedrock topography, outcrops, and sediment thickness. In addition, early planning is underway for an effort to prepare a new State surficial geological map to succeed the existing map produced in 1982.

Web-Optimized Detailed Geological Mapping Layers

While statewide maps of surficial and bedrock geology have been made available and are being updated to clarify context, it is mapping at 1:100,000 and 1:24,000 scale that is used for management applications at the county and local scale. Paper maps are still required, although many users rely on GIS resources and the Web to obtain information that they need on a day to day basis for their jobs. Standard geological maps with intricate legends, on paper or obtained by time-consuming download, are not optimal for users who prefer to quickly obtain information and make decisions from a Web interface; with that said, these maps will remain the authored, peer-reviewed foundation of our system. New detailed geological mapping layers, optimized for efficient Web query and accessibility are the new goal, with the added benefit that these layers can also act as the future gateway to more thorough documentation of standard maps and reports.

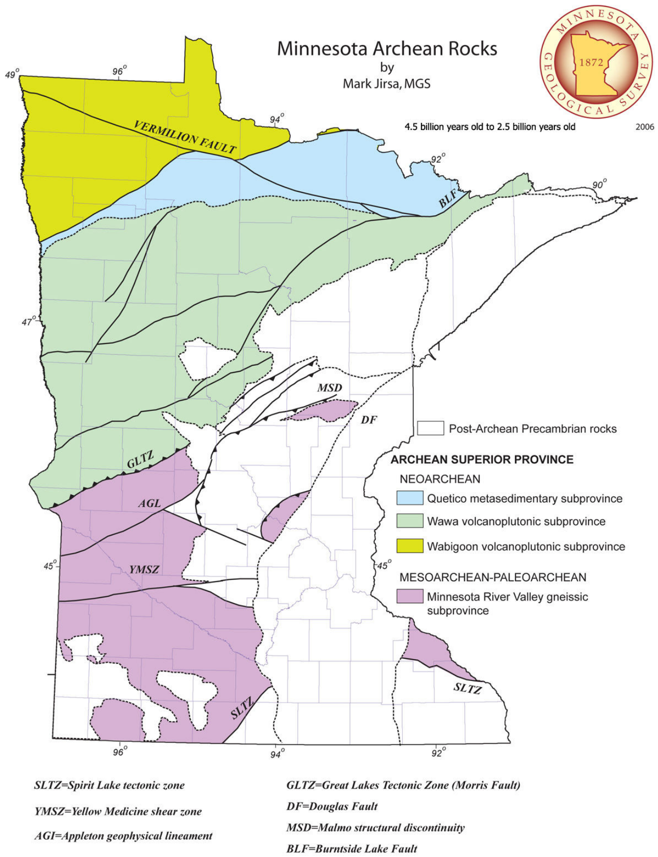

Figure 13. The basement layer of the new GIS-based State bedrock map will largely consist of Archean rocks.

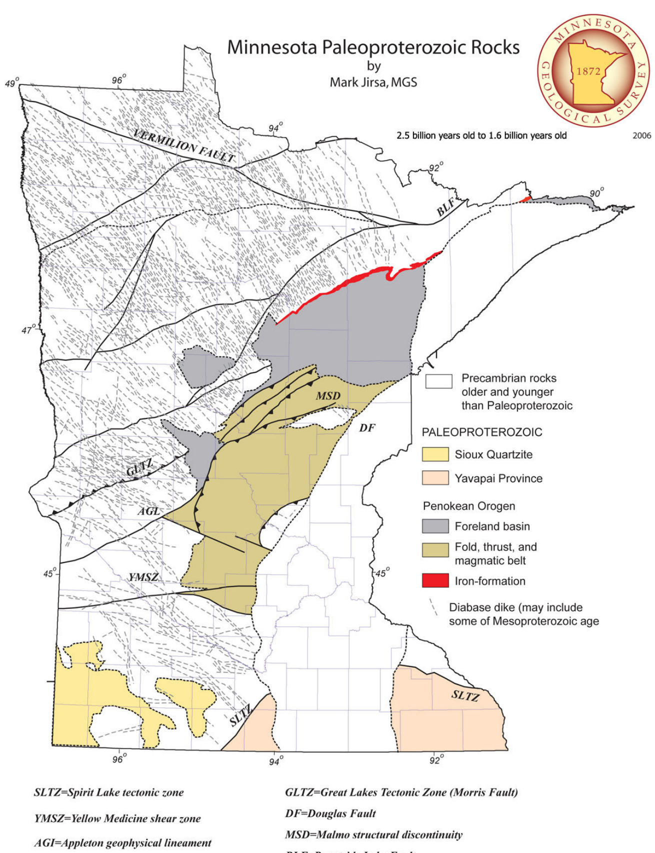

Figure 14. The Paleoproterozoic layer of rocks in the new State bedrock map.

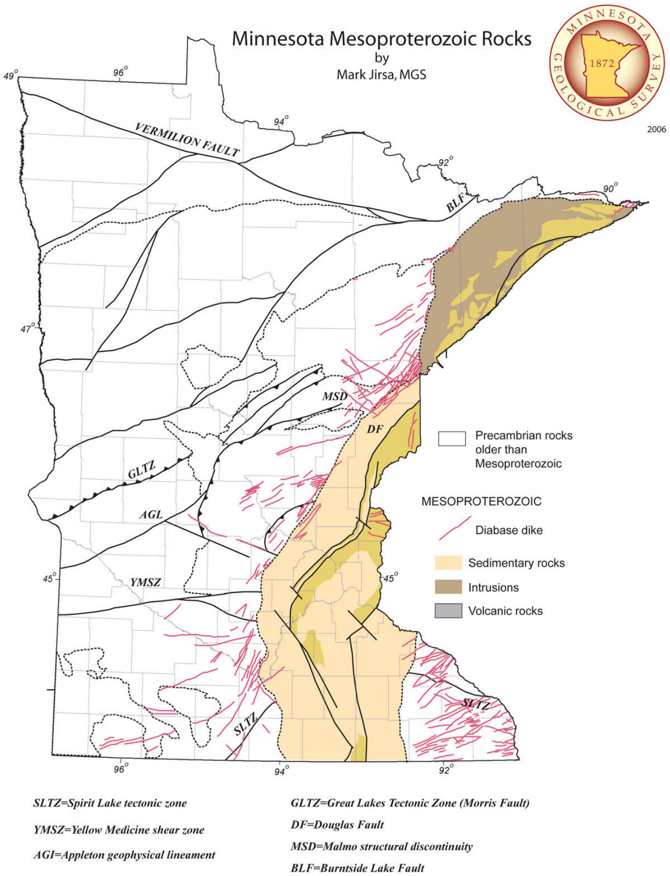

Figure 15. The Mesoproterozoic rocks in the new State bedrock map.

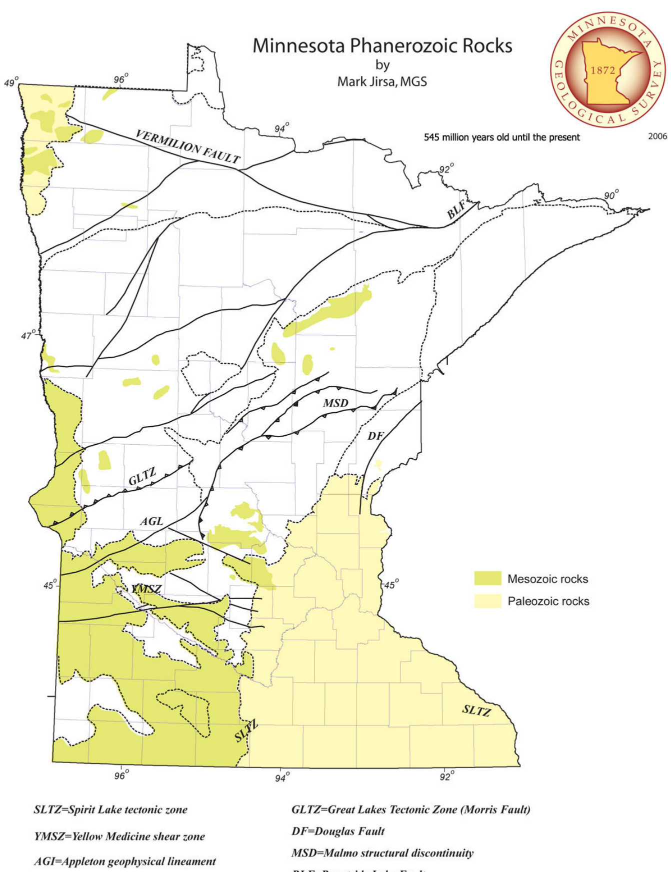

Figure 16. The Paleozoic and Mesozoic rocks in the new State bedrock map.

Statewide raster mosaics of existing detailed 1:100,000- and 1:24,000-scale surficial and bedrock geological maps thus will soon be prepared as a Web services initiative, initially to be a part of the international OneGeology project, but with plans for gradual vector digitization, harmonization, and enhancement of the mapping (fig. 17). Any statewide compilation of detailed mapping will, however, be incomplete for many years, and when complete, remapping will call for the pace of mapping to be maintained or increased. Focus therefore will remain on the maintenance and enhancement of sound field mapping skills, the steady progress of new field work, and production of new geological maps that will take us closer to eventual completion and enhancement of statewide detailed geological mapping coverage at a 1:100,000 scale or more detailed.

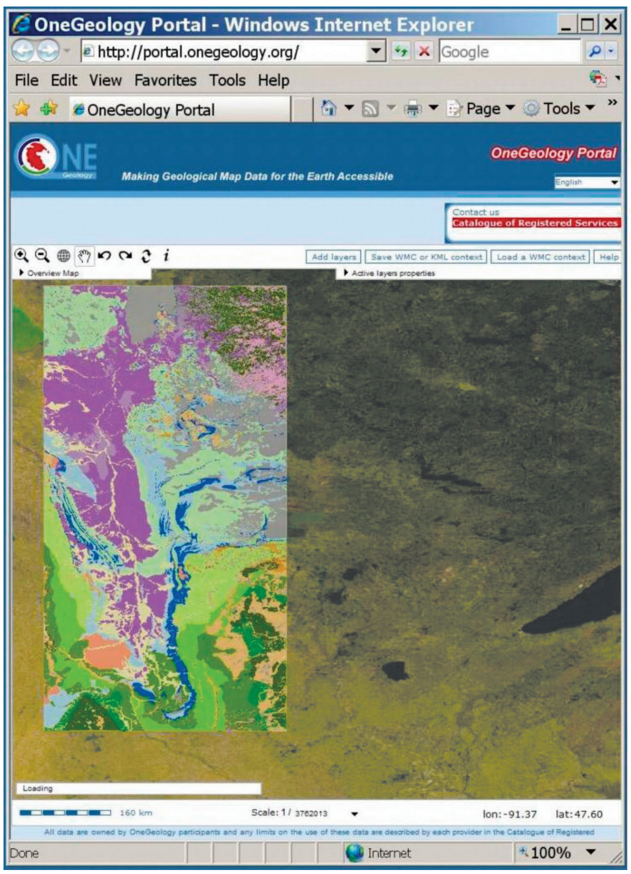

Figure 17. Compilation of detailed mapping has begun in cooperation with Manitoba Geological Survey; here, Red River Valley surficial geology is being viewed, and the screen extends east to Lake Superior.

County Geologic Atlases

MGS is steadily increasing its focus on the County Geologic Atlas program (fig. 18), managed in partnership with the DNR. These sets of 1:100,000-scale maps include bedrock geology, surficial geology, bedrock topography, depth-to-bedrock, and subsurface geology. The atlases have become progressively more digital and three dimensional. The MGS atlas products cost from $300,000 to $400,000 per county, depending on the size, geological complexity, and database size. The DNR spends a roughly equivalent sum on its products largely related to groundwater resources. The county shares in the cost of each atlas. Currently 20 counties have a completed atlas, and one of the early atlases from the 1980s has been updated as a result of financial support from that county; 6 other counties have atlases underway and 5 more are in the planning stage. The Minnesota Legislature has committed itself to enhanced groundwater protection, and the County Geologic Atlas program is seen as essential to achieving that objective.

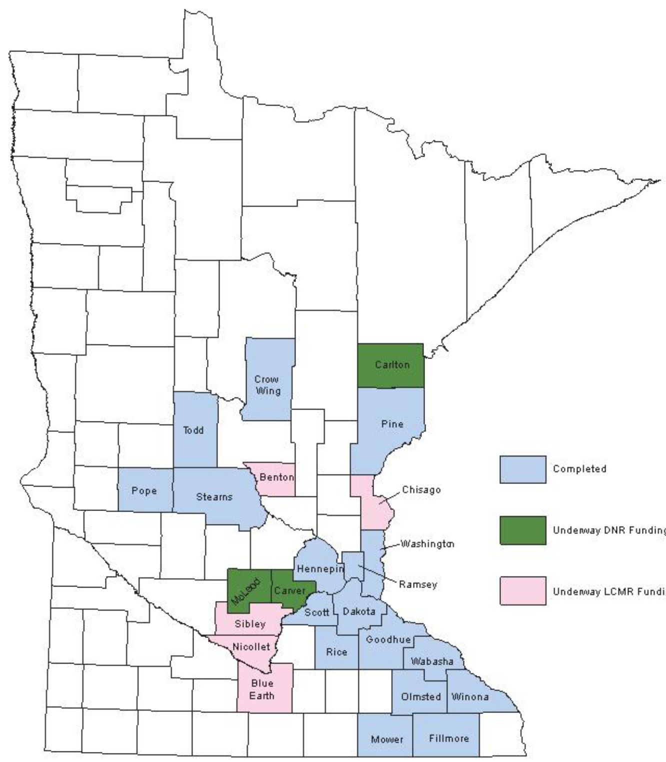

Figure 18. The principal Minnesota Geological Survey program is production of multi-layered 1:100,000 County Geologic Atlases, complete for about a third of the State. "DNR" is the MN Dept. of Natural Resources; "LCMR" has now become the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

County atlas plates are still offset printed, and MGS and its partners are committed to this high quality production of paper maps and their digital counterparts. These plates can include the database map, bedrock geology map, surficial geology map, subsurface geology depicted as cross sections and structure contours and isopachs, bedrock topography, depth to bedrock, and modeling of sand bodies as sources of drinking water.

Increasingly, however, the most important County Geologic Atlas product is the package of GIS resources that is distributed by DVD or ftp. These resources allow GIS managers to work with and query the entire database, including data for individual water wells. MGS has not yet developed protocols for version numbering and long-term maintenance of these GIS resources, nor are these materials optimized for Web accessibility. In the long-term, effort will also be directed at linking the atlases together. These opportunities and challenges will draw increasing attention in the months and years ahead.

Information Delivery

While publication sales, the Web site, and ftp are being maintained, current intentions are to shift information products to Open Geospatial Consortium-compliant Web Services. This will allow users either to gain access to MGS products through the conventional MGS Web site or to gain direct access to the data through their preferred GIS platform or Web interface.

Acknowledgments

In addition to the ongoing dedication of Minnesota Geological Survey staff, support from the Minnesota State Legislature, the University of Minnesota, the Legislative-Citizen Commission on Minnesota Resources (LCCMR), the Minnesota Minerals Coordinating Committee, the Statemap component of the National Cooperative Geological Mapping Program, the USGS Data Preservation program, and partners throughout the State that makes this work possible is acknowledged and deeply appreciated.

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Geologic Resources Inventory of Our National Parks: A Case Study of the Timpanogos Cave National Monument

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Introduction

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the National Park Service (NPS) Natural Resource Challenge. It is designed to enhance baseline information available to park managers. The Geologic Resources Division (GRD) of the Natural Resource Program Center administers this program. To develop its products, the GRI team relies heavily on partnerships with Colorado State University (CSU), the U.S. Geological Survey, individual State geological surveys, and other organizations. The goals of the GRI are to increase understanding of the geologic processes that affect the parks and to provide accurate geologic information for use in park decisionmaking. Sound park stewardship relies on understanding natural resources and their role in the ecosystem, of which geology is the foundation.

CSU plays an integral role in creating and developing geologic products for use in managing the natural resources of the parks. CSU research associates work side-by-side with GRD staff, attending scoping meetings at parks to identify mapping needs and park-specific geologic issues, features, and processes. Research associates then produce a record of those meetings in a scoping summary, write geologic reports about the park's geology, and create digital geologic-GIS data for use by park staff. CSU research associates have taken the lead in creating the NPS GRI Geology-GIS Geodatabase Data Model (O'Meara and others, 2008) to detail a series of guidelines for the capture and presentation of the geologic-GIS data. In addition, CSU research associates designed the map unit properties table, which provides a link between the properties of the geologic units on the digital map and the geologic information in the report.

This paper presents the GRI map and report products created for Timpanogos Cave National Monument (TICA), focusing on the Mississippian Deseret Limestone and its implications for park resource management.

Scoping

CSU Research Associates participated in a GRI scoping meeting at TICA (see figure 1, Location Map of Timpanogos Cave National Monument, Utah), which involved a site visit and roundtable discussion. The purpose of this meeting was to (1) introduce the GRI program and products, (2) investigate and evaluate existing geologic map coverage and potential mapping needs, (3) discuss geologic resource management issues and potential research and monitoring needs, and (4) identify distinctive geologic features and processes at the monument (for example, see figure 2). The scoping meeting included geologists and local experts from the NPS, Utah Geological Survey, University of Arizona, Brigham Young University, and TICA. A scoping summary generated from discussions at the meeting included:

- Brief description of the GRI
- Overview of the monument's geologic setting and geologic resources
- Status of mapping coverage and plan for producing the digital geologic map
- Prioritized list of geologic resource management issues

- Description of geologic features and processes of interest
- Lists of research and monitoring recommendations and action items
- Participant list and contact information.

This summary served as an interim geologic report for the monument until the GRI produced the digital geologic map and accompanying final geologic report. The GRI scoping summary for TICA is available for download at *http://www.nature.nps.gov/geology/inventory/publications/s_summaries/TICA_scoping_summary_19990813.pdf*.

Map and Report Production Process

At the scoping meeting for TICA, participants decided that no new mapping was needed to meet the resource management needs of the park and that the digital geologic map for the monument should include the entire Timpanogos Cave quadrangle from the paper map produced by Baker and Crittenden (1961). In general, after available maps are identified, paper maps are scanned at high resolution and digitized, or available digital data are converted to the NPS GRI Geology-GIS Geodatabase Data Model (O'Meara and others, 2008), which specifies standards for attribution and spatial relationships, incorporating topological rules, subtypes, domains, and relationship classes. The goal is to maintain all aspects of the original paper map or data while enhancing usability by providing all elements of the map in a compact digital format that is usable in ArcGIS (*http://www.esri.com*). For TICA, cross sections were provided as separate images linked from ArcMap. Additional information found on the source paper map, such as its report, legend, and references, was included in the accompanying map information document, in Adobe Acrobat PDF format. GIS data layers digitized from the map included attitude measurements, faults, folds, geologic units and contacts, mine features, cross sections, and map symbology. In addition, two tables containing information about the geologic units and source map references were produced. In addition to the GIS data and map information document, the final digital geologic map product for TICA included layer files that record the symbology for each geologic data layer, and FGDC-compliant metadata.

Once the GRI had completed and distributed the digital geologic map for TICA, CSU research associates began production of the final geologic report. The GRI intended the geologic report for TICA to be concise and accessible to non-geoscientists. Information from the digital geologic map (including unit descriptions) and the scoping summary served as the foundation for the report. Through additional research, information from resources such as park planning documents, geologic journals, professional communication with local experts, park-specific publications, and the TICA Web site, were incorporated. The final report included a map unit properties table, which describes each unit that appears on the digital geologic map and delineates geologic properties of interest to monument resource managers. This table serves as a direct connection between the report and digital geologic map. The final geologic report underwent an extensive review

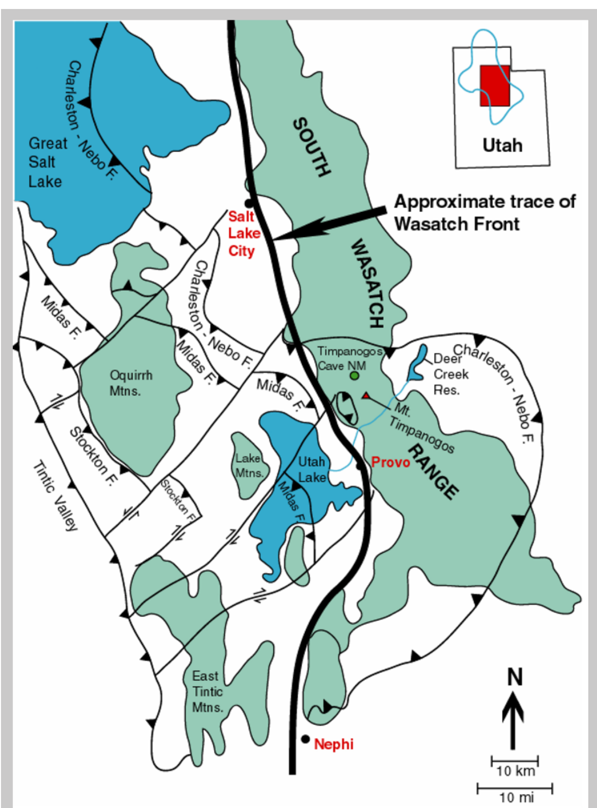


Figure 1. Location Map of Timpanogos Cave National Monument, Utah.

Figure 2. Speleothems in Middle Cave, Timpanogos Cave National Monument (photograph by NPS).

process with input from park staff and GRD technical experts, and final copyediting. Once finalized, the NPS-GRD delivered a hard copy of the GRI report for TICA accompanied by a CD containing a transmittal letter, PDF image of the digital geologic map, guide for using GIS data, the digital geologic map data, an ArcGIS geologic map document (.mxd), the GRI Geology-GIS Geodatabase Data Model, and a PDF of the geologic report.

Map Products

For TICA, the GRI program produced the following map products: GIS data, metadata and readme files, ancillary tables, and map help document. GIS data were delivered in both ESRI Personal Geodatabase and shapefile formats with attribute tables for both formats conveying information about the characteristics and properties of mapped geologic features. These data were accompanied by layer files (.lyr) that display geologic map symbology for individual data layers, and an ArcGIS map document (.mxd) that presents all GIS components of the GRI digital geologic map for Timpanogos Cave in a user-friendly format for viewing and data analysis. The FGDC-compliant metadata (.txt) conveyed layer and map-specific information such as data origin, data scale, how the data were created and the intended use, and whom to contact with questions about the data. The GIS Data Explanation readme file (in .pdf format) described the contents of the GRI GIS product with recommended entry points for viewing and using the data. Several ancillary tables were produced, including the Geologic Unit Information Table and the Source Map Information Table. The Geologic Unit Information Table displays detailed name and age information for geologic units in the map area. The Source Map Information Table contains citation information for all mapping data used in the creation of the GIS data. Both tables were linked through a relationship class, to be viewed with the GIS data in ArcMap. The GRI Map Help Document (.pdf) is intended to supplement the GIS data by providing lithologic descriptions, legends, figures, tables, and citation information from source maps used for this park. The Map Help Document contains information about the GRI program and about the methods and formats employed in the creation of the GIS data, and uses links within the document to enable easy and logical navigation. The GRI map products described above are available for download from the NPS Data Store (*http://science.nature.nps.gov/nrdata*).

Additional products created for TICA included a map layout and cross section graphics. The map layout is a .pdf-format representation of the GIS data; it contains standard geologic map elements such as legends, correlation of units, scale, and so on and is available for download from *http://www.nature.nps.gov/geology/inventory/publications/map_graphics/tica_map_graphic.pdf*. Images of geologic cross sections are annotated with citation information and linked to the geologic cross sections in the GIS data.

The GIS data provide information about the geology of the TICA and surrounding area. The Timpanogos cave complex is composed of three caves called Hansen, Middle, and Timpanogos caves, two of which are shown in figure 3A. The caves formed in the Mississippian Deseret Limestone (Md) through persistent dissolution of the limestone by acidic water along groundwater paths of concentrated flow. The Deseret Limestone is represented in the GIS data with color-filled polygons (defined by the Unit Symbol, fig. 3A), and an attribute table describing basic information about it and other geologic units (fig. 3B). An attribute table describing

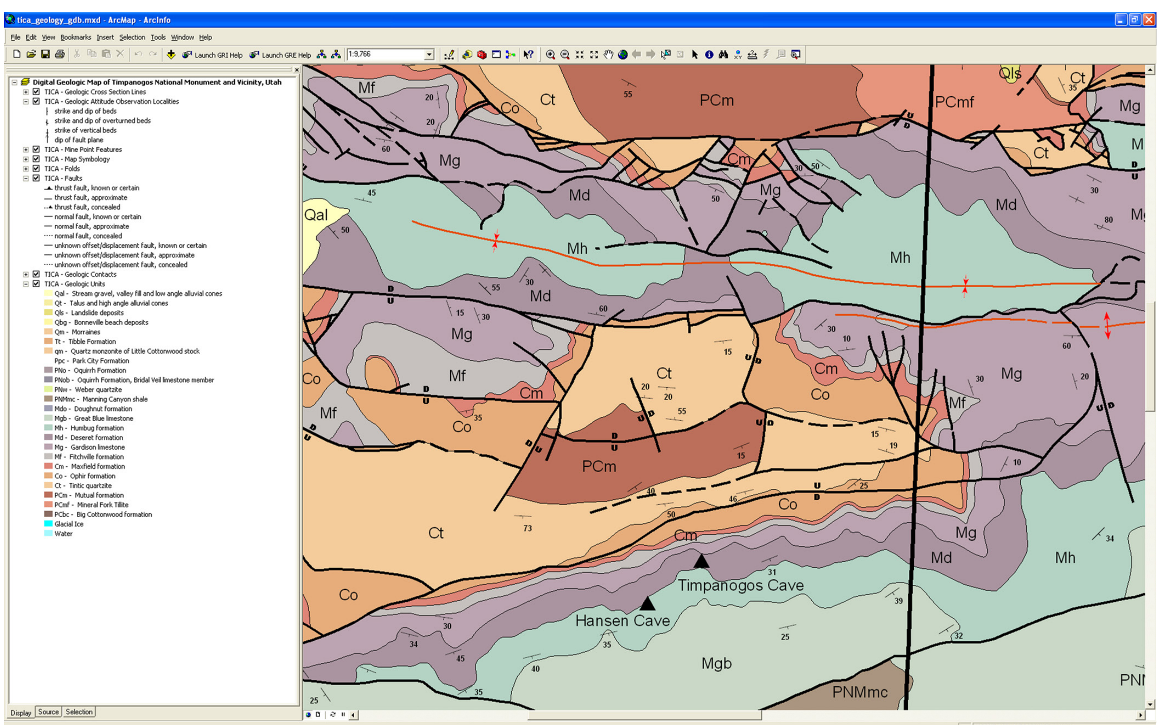
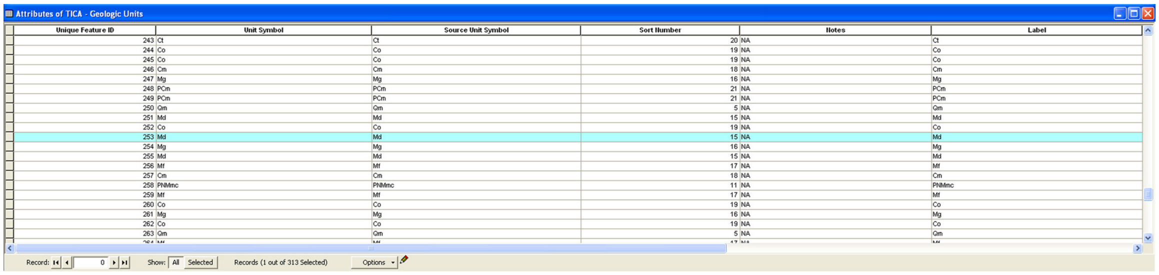
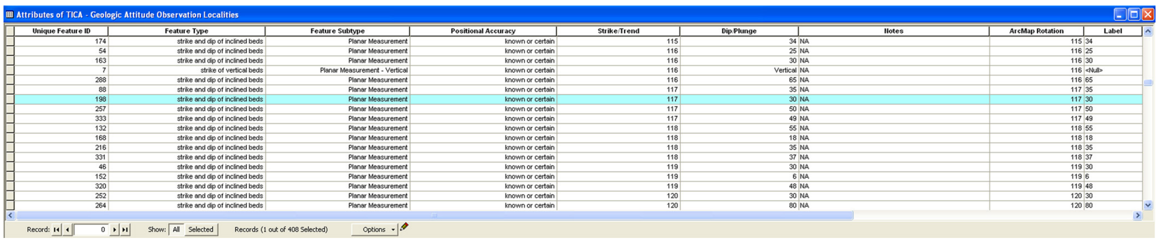


Figure 3A. ArcGIS geologic map document (.mxd) for part of Timpanogos Cave National Monument.



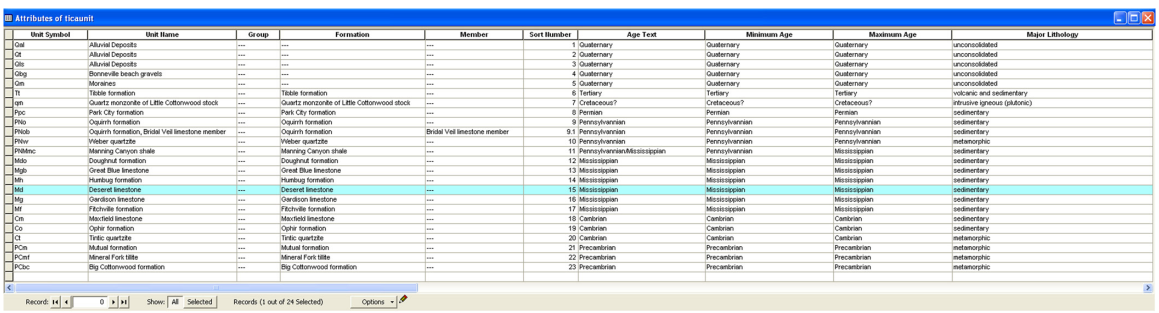
Unique Feature ID	Unit Symbol	Source Unit Symbol	Sort Number	Notes	Label
243	Ct	Ct	20	NA	Ct
244	Co	Co	19	NA	Co
245	Co	Co	19	NA	Co
246	Cm	Cm	18	NA	Cm
247	Mg	Mg	16	NA	Mg
248	PCm	PCm	21	NA	PCm
249	PCm	PCm	21	NA	PCm
250	Qm	Qm	5	NA	Qm
251	Md	Md	15	NA	Md
252	Co	Co	19	NA	Co
253	Md	Md	15	NA	Md
254	Mg	Mg	16	NA	Mg
255	Md	Md	15	NA	Md
256	Mf	Mf	17	NA	Mf
257	Cm	Cm	18	NA	Cm
258	PNMmc	PNMmc	11	NA	PNMmc
259	Mf	Mf	17	NA	Mf
260	Co	Co	19	NA	Co
261	Mg	Mg	16	NA	Mg
262	Co	Co	19	NA	Co
263	Qm	Qm	5	NA	Qm

Figure 3B. Geologic Units Attribute Table.



Unique Feature ID	Feature Type	Feature Subtype	Positional Accuracy	Strike/Trend	Dip/Plunge	Notes	ArcMap Rotation	Label
174	strike and dip of inclined beds	Planar Measurement	known or certain	115	34	NA	115	34
54	strike and dip of inclined beds	Planar Measurement	known or certain	116	25	NA	116	25
163	strike and dip of inclined beds	Planar Measurement	known or certain	116	30	NA	116	30
7	strike of vertical beds	Planar Measurement - Vertical	known or certain	116	Vertical	NA	116	<Null>
288	strike and dip of inclined beds	Planar Measurement	known or certain	116	65	NA	116	65
88	strike and dip of inclined beds	Planar Measurement	known or certain	117	35	NA	117	35
198	strike and dip of inclined beds	Planar Measurement	known or certain	117	30	NA	117	30
257	strike and dip of inclined beds	Planar Measurement	known or certain	117	50	NA	117	50
333	strike and dip of inclined beds	Planar Measurement	known or certain	117	49	NA	117	49
132	strike and dip of inclined beds	Planar Measurement	known or certain	118	55	NA	118	55
168	strike and dip of inclined beds	Planar Measurement	known or certain	118	18	NA	118	18
216	strike and dip of inclined beds	Planar Measurement	known or certain	118	35	NA	118	35
331	strike and dip of inclined beds	Planar Measurement	known or certain	118	37	NA	118	37
46	strike and dip of inclined beds	Planar Measurement	known or certain	119	30	NA	119	30
152	strike and dip of inclined beds	Planar Measurement	known or certain	119	6	NA	119	6
320	strike and dip of inclined beds	Planar Measurement	known or certain	119	48	NA	119	48
252	strike and dip of inclined beds	Planar Measurement	known or certain	120	30	NA	120	30
264	strike and dip of inclined beds	Planar Measurement	known or certain	120	80	NA	120	80

Figure 3C. Geologic Attitude Observation Localities Table.



Unit Symbol	Unit Name	Group	Formation	Member	Sort Number	Age Text	Minimum Age	Maximum Age	Major Lithology
Qal	Alluvial Deposits	---	---	---	1	Quaternary	Quaternary	Quaternary	unconsolidated
Qt	Alluvial Deposits	---	---	---	2	Quaternary	Quaternary	Quaternary	unconsolidated
Qls	Alluvial Deposits	---	---	---	3	Quaternary	Quaternary	Quaternary	unconsolidated
Qbg	Bonneville beach gravels	---	---	---	4	Quaternary	Quaternary	Quaternary	unconsolidated
Qm	Moraines	---	---	---	5	Quaternary	Quaternary	Quaternary	unconsolidated
Tt	Tibble formation	---	Tibble formation	---	6	Tertiary	Tertiary	Tertiary	volcanic and sedimentary
qm	Quartz monzonite of Little Cottonwood stock	---	Quartz monzonite of Little Cottonwood stock	---	7	Cretaceous?	Cretaceous?	Cretaceous?	intrusive igneous (plutonic)
Ppc	Park City formation	---	Park City formation	---	8	Permian	Permian	Permian	sedimentary
PNo	Oquirrh formation	---	Oquirrh formation	---	9	Pennsylvanian	Pennsylvanian	Pennsylvanian	sedimentary
PNob	Oquirrh formation, Bridal Veil limestone member	---	Oquirrh formation	Bridal Veil limestone member	9.1	Pennsylvanian	Pennsylvanian	Pennsylvanian	sedimentary
PNw	Weber quartzite	---	Weber quartzite	---	10	Pennsylvanian	Pennsylvanian	Pennsylvanian	metamorphic
PNMmc	Manning Canyon shale	---	Manning Canyon shale	---	11	PennsylvanianMississippian	Pennsylvanian	Mississippian	sedimentary
Mdo	Doughnut formation	---	Doughnut formation	---	12	Mississippian	Mississippian	Mississippian	sedimentary
Mgb	Great Blue limestone	---	Great Blue limestone	---	13	Mississippian	Mississippian	Mississippian	sedimentary
Mh	Humbug formation	---	Humbug formation	---	14	Mississippian	Mississippian	Mississippian	sedimentary
Md	Deseret limestone	---	Deseret limestone	---	15	Mississippian	Mississippian	Mississippian	sedimentary
Mg	Gardison limestone	---	Gardison limestone	---	16	Mississippian	Mississippian	Mississippian	sedimentary
Mf	Fitchville formation	---	Fitchville formation	---	17	Mississippian	Mississippian	Mississippian	sedimentary
Cm	Maxfield limestone	---	Maxfield limestone	---	18	Cambrian	Cambrian	Cambrian	sedimentary
Co	Ophir formation	---	Ophir formation	---	19	Cambrian	Cambrian	Cambrian	sedimentary
Ct	Tintic quartzite	---	Tintic quartzite	---	20	Cambrian	Cambrian	Cambrian	metamorphic
PCm	Mutual formation	---	Mutual formation	---	21	Precambrian	Precambrian	Precambrian	metamorphic
PCmf	Mineral Fork tillite	---	Mineral Fork tillite	---	22	Precambrian	Precambrian	Precambrian	metamorphic
PCbc	Big Cottonwood formation	---	Big Cottonwood formation	---	23	Precambrian	Precambrian	Precambrian	metamorphic

Figure 4. Geologic Unit Information Table.

the highly inclined bedding near the caves is also presented (fig. 3C). Additional information about the unit, including its age, name, and whether it is a Group, Formation, or Member, is shown in the Geologic Unit Information Table (fig. 4). Finally, a unit description for the Deseret Limestone (Md) and other units, as well as geologic cross sections and other additional source map information, is presented in the GRI Map Help PDF document (figs. 5A and 5B).

Report Products

The GRI geologic report produced for TICA includes the following sections and components: Executive Summary and Introduction, Geologic Issues, Geologic Features and Processes, Map Unit Properties Table, Geologic History, Glossary and References, and Appendices. The Executive Summary and Introduction contains a summary of the key points in the report and describes the GRI program, geologic setting and history of TICA, and cave formation at Timpanogos. The Geologic Issues section describes resource management issues such as seismicity associated with the Wasatch Front, mine features, slope processes, cave restoration and preservation, wind erosion, sediment loading, and stream flow with issue-specific recommendations for inventory, monitoring, and research. The Geologic Features and Processes section describes the Charleston Fault Zone, formation of the cave and karst landscapes, and speleothems at TICA. The Map Unit Properties Table presents physical characteristics, potential resources, cultural information, and scientific significance of each unit on the geologic map. The Geologic History section describes the rocks and unconsolidated deposits that appear on the geologic map, the environment in which those units were deposited, and the timing of geologic events that created the present landscape. Technical geologic terms used throughout the report are defined in the Glossary. The Reference section lists the sources cited in the report and provides a general

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Geologic Resources Inventory Map Document for Timpanogos Cave National Monument

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Figure 5A. Table of Contents, in Map Help Document.

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Although the Fitchville rests, in the Wasatch Mountains, on Cambrian rocks that range from the upper part of the Maxfield to the lower member of the Ophir, the unconformity at its base is rarely marked by noticeable angular discordance of beds, the largest thus far observed (in the Cottonwood area) being about 10°.

The basal beds of the Fitchville, 2 to 10 feet thick, generally consist of tan-weathering crossbedded flaggy dolomitic sandstone and sandy dolomite containing well-rounded frosted quartz grains up to 2 mm in diameter, and, in some places, quartz pebbles as much as an inch in diameter. The rest of the formation consists mainly of two thick layers of massive dolomite, separated in some places by a few feet of rock resembling that at the base but nowhere pebbly. The lower massive layer is light to medium gray on weathered surfaces; the upper, which is partly detrital, is dark gray. The formation contains a good many vugs, especially in the thin-bedded carbonate layers. At the top of the Fitchville, as mapped in this quadrangle, is a persistent bed of very fine grained dolomite, medium-light gray on fresh fractures but nearly white on weathered surfaces. In most of the area it is a single bed 15 inches to 3 feet thick, but in a few places it splits into two or three thinner beds.

Gardison Limestone

The Fitchville formation is conformably overlain by a thick sequence of limestone and dolomite correlated with the Gardison limestone, of Early Mississippian age, in the Tintic district (Morris and Lovering,1960).These beds were formerly called Madison, but since the unit does not include the lowest Mississippian beds, that term is now considered to be inappropriate.

The Gardison comprises, in ascending order: (1) 10 to 30 feet of dark-gray coarse-grained crossbedded dolomite, (2) 80 to 100 feet of thin-bedded blue-gray limestone with tan-weathering silty partings, which forms a strongly banded unit in part highly fossiliferous, and (3) about 400 feet of dark-gray massive limestone and dolomite, enclosing roughly tabular masses of white chert 2 to 4 inches thick, which become increasingly abundant upward. The top of the formation is drawn at the base of a thin black carbonaceous shale. In some places, where that bed is absent or concealed, it has been drawn at the base of a zone of platy-weathering shaly limestone that is about 100 feet higher in the section. The total measured thickness of the Gardison in Box Elder Canyon and near the mouth of American Fork Canyon is about 600 feet.

Deseret Limestone

The Gardison limestone is overlain conformably by a massive cliff-forming unit correlated with the Deseret limestone of the Oquirrh Mountains. This formation, in which Timpanogos Cave is located, consists of light- to dark-gray fine- to coarse-grained dolomite with abundant lenticular chert. It was found to be 420 feet thick in Box Elder Canyon. The base of the formation is drawn at the base of one thin phosphatic and slightly uraniferous black shale noted above, wherever that bed can be recognized. In most places the Deseret contains only a few scattered fossils-mainly brachiopods and syringoporoid corals-and, largely on the basis of collections from the type locality, is generally regarded as entirely of Late Mississippian age. In this area, however, platy-weathering silty limestones which form a marked bench 100 to 200 feet above the base of the formation opposite the mouth of Little Mill Canyon contain a large and distinctive fauna which Mackenzie Gordon and J. T. Dutro (written communication, 1959) assign to the Osage (Early Mississippian). The upper part of the Deseret, though nowhere so fossiliferous, is still assumed to be Late Mississippian.

Humbug Formation

The Deseret limestone is conformably overlain by the Humbug formation, which is characterized by an alternation of tawny-weathering fine- to medium-grained limy sandstone with thin- to thick-bedded fine- to coarse-grained limestone and dolomite. The base of the Humbug is arbitrarily placed at the lowest persistent bed of sandstone. A variable thickness of pale-gray limestone relatively free from sandstone is included at the top of the Humbug beneath the lowest dark shale, dark limestone, or thin beds of

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Figure 5B. Description of geologic units, in Map Help Document.

bibliography for use by the resource manager. Appendix A contains the geologic map graphic, which is an 11 by 17-inch browse graphic of the digital geologic map of TICA. Appendix B includes excerpts from the scoping summary. The GRI Geologic Report for TICA is available for download from *http://www.nature.nps.gov/geology/inventory/publications/reports/tica_gre_rpt_view.pdf*.

The GRI report makes the information in the GIS data more relevant and accessible to park resource managers by providing resource-specific information about each geologic unit, and the geologic setting. The Map Unit Properties Table (fig. 6) shows this information more graphically and ties back to the map product by replicating the color of the unit as it appears on the GIS map (fig. 3A).

Resource Management Implications

CSU research associates and GRD staff provided TICA staff with a complete GRI product including a summary of the scoping meeting, digital geologic-GIS data, and the geologic report summarizing the park's geologic issues, features, and processes. The Deseret Limestone is of particular significance because it is the geologic unit that hosts the majority of the cave complex at the national monument (figs. 7 and 8). The GIS data can be used to understand the spatial distribution of the Deseret Limestone, thereby identifying other potential locations of cave formation. The geologic report provides additional detailed information about the unit and its particular properties. Combining information from the GIS data and the report, park resource managers have a powerful tool for determining which locations are suitable for development, which areas need resource protection, and where potential hazards may exist.

At TICA, the Deseret Limestone is relatively resistant to weathering and erosion, forming steep slopes. The limestone is unsuitable for development in areas where dissolution is high, because pervasively dissolved areas do not provide the structural integrity for heavy development nor do they provide the adsorption capabilities necessary for wastewater treatment. The unit is also fossiliferous, posing the potential need to develop a resource management plan to protect exposures of the Deseret Limestone from park visitors in search of fossil samples. In addition, the information contained in the report and GIS data can be used to help identify habitats for various plants and animals. For instance, the caves within the Deseret Limestone may provide habitat for mountain lions as well as cave flora and fauna. The mineralized caves at Timpanogos (fig. 9) are famous for myriad speleothems including rare examples of helictites. Trace elements derived from units such as the Deseret Limestone are responsible for the variety of colored dripstones and flowstones. Geochemical sampling of Deseret Limestone and associated speleothems may yield paleoclimate information and data regarding the timing of cave formation. The GRI product is an informative component available to park interpretive staff for creating programs designed to educate monument visitors about the geology of the area.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Specimens	Karst Issues	Mineral Resources	Habitat	Recreation	Global Significance
MISSISSIPPIAN	Great Blue Limestone (Mgb)	Unit is 853 m (2800 ft) thick, informally divided into three parts: lower and upper limestone members, separated by carbonaceous shaly beds (Long Trail shale member). Unit is composed of nearly homogenous, calcitic, dark gray to black limestone and shaly limestone. Bedding is very regular and weathers to light-gray to pinkish-tan flaky, slabby rock. Some black chert nodules occur locally as well as some black shale and rusty weathering fine-grained quartzite.	Moderate	Suitable for most development unless significant dissolution or weathering has occurred. Weathered rock sloughs and flakes and is unstable for permanent structures. Dissolution can pose a problem with waste facilities	Rockfall hazard where unit is weathered and on a slope, can be unstable trail base if severely weathered or dissolved.	Late Mississippian age fossils	Chert nodules could have provided tool material	None	Karst potential exists for this unit	None documented	Vugs on cliff could provide nesting habitat	Good for most uses, weathered surfaces could prove hazardous for rock climbing.	Type locality in the Oquirrh Mountains
MISSISSIPPIAN	Humbug Formation (Mh)	Unit is more than 244 m (800 ft) thick in TICA area. Composed of interbanded dark to light-gray, fine- to coarse-grained dolomite with fine- to medium-grained limey sandstone. Unit appears banded with brown beds layered with gray beds.	Moderate	Good for all development unless highly fractured, which could pose a problem with waste facilities	Rockfall hazard on cliff faces	sparsely fossiliferous in limestone beds	None	None	Karst potential exists for this unit	Attractive building stone	Vugs and ledges on cliffs could provide nesting habitat	Rock climbing and Mountain biking. Good for all uses	Distinct banded unit
MISSISSIPPIAN	Deseret Limestone (Md)	The unit is more than 152 m (500 ft) thick. Unit is a massive to medium-bedded, cliff and cave-forming unit with dark- to light-blue-gray, fine- to coarse-grained dolomite with abundant lenticular, or lens-like, black chert deposits and some interbedded limestone. Timpanogos Cave is contained in this unit.	Moderate to high	Dissolution can create conduits which pose a problem for waste facilities and severe dissolution can make construction on this unit risky	Rockfall on cliff faces, and assorted cave-related hazards such as slippery trails, holes, and sharp speleothems	Late Mississippian age brachiopods and corals, crinoid stems, cup corals and colonial corals.	Native Americans may have used the caves for ceremonial and other purposes, chert masses may have been tool material	Speleothems, fossils	Karst exists in this unit, caves present	None documented	Caves provide animal lion and other mammal habitat	Caving, climbing	Cave and cave formations (speleothems)
MISSISSIPPIAN	Gardison Limestone (Mg)	Unit is more than 183 m (600 ft) thick in monument area. Lower beds are dark-gray, thin-bedded, coarse-grained limestone and dolomite. Middle beds contain thin-bedded, blue-gray limestone with silty partings. Upper beds are dark-gray, massive limestone and dolomite. Light-brown to black, and white chert abundant locally. Carbonaceous shale marks top of unit.	Moderate to high	Shaly partings can render the unit unstable for foundations and other permanent facilities	Shaly partings can pose rockfall hazards	Fossils of *Triplophyllites, Syringopora, Spirifer centronatus*, *Triplophyllites excavatum*, *Cliothyridina* and *Aviculipecten* of Mississippian age.	Many chert nodules useful for ancient tools	Fossils	Some karst potential in carbonate beds	Locally uraniferous and phosphatic layers	Vugs on cliff could provide nesting habitat	Good for all uses	Mississippian fossils of Kinderhookian age
MISSISSIPPIAN	Fitchville Dolomite (Mf)	In the TICA area the unit is more than 152 m (500 ft) thick, composed of coarse, light-gray to tan dolomite and dolomitic sandstone with some pebbly layers. Upper beds are very fine-grained dolomite.	Low to moderate	Dissolution can create water conduit problems and dangerous trail base, but otherwise okay for all uses	Jointed sandstone beds can pose rockfall hazards on cliffs, crystal lined vugs are hazardous hand and foot holds	Mississippian age fossils	None	Crystal lined vugs	Karst potential exists for this unit	Flaggy lower beds are attractive flagstone material	Many vugs present for bird and small creature habitat	Rock climbing and caving potential	Mississippian fossils, records profound unconformity
CAMBRIAN	Maxfield Limestone (Cm)	Unit ranges in thickness between 0 and 91 m (0-300 ft). Unit contains thin- to thick-bedded, blue-gray, mottled or speckled magnesian limestone and dolomite. Some oolitic and pisolitic lower beds and white dolomite upper beds	Moderate	Dissolution can create hazardous trail base and conduits not suitable for waste facilities.	Rockfall hazard potential	Fossils of trilobites *Kootenia* sp., *Doliochometopsis* sp., *Spencia* sp.	None	Fossils, pisolite layers	Karst potential exists for this unit	None documented	Vugs on cliff could provide nesting habitat	Rock climbing potential	Cambrian fossils
CAMBRIAN	Ophir Formation (Co)	Near TICA unit is 91 m (300 ft) thick. Lower beds are olive-green micaceous shale. Middle beds are massive gray limestone and upper beds are brown, calcareous sandstone mixed with shale.	Low	Micaceous shale can be unstable for structure foundations	Unit can be a crumbly trail base	worm tracks, fucoid markings, brachiopods and trilobites. Fossils of *Olenellus, Micromitra, Obolus*	None	Fossils	Middle beds may have dissolution	None documented	Vugs on cliff could provide nesting habitat	Good for trails	Cambrian fossils

Figure 6. Map Unit Properties Table, from the Geologic Report.

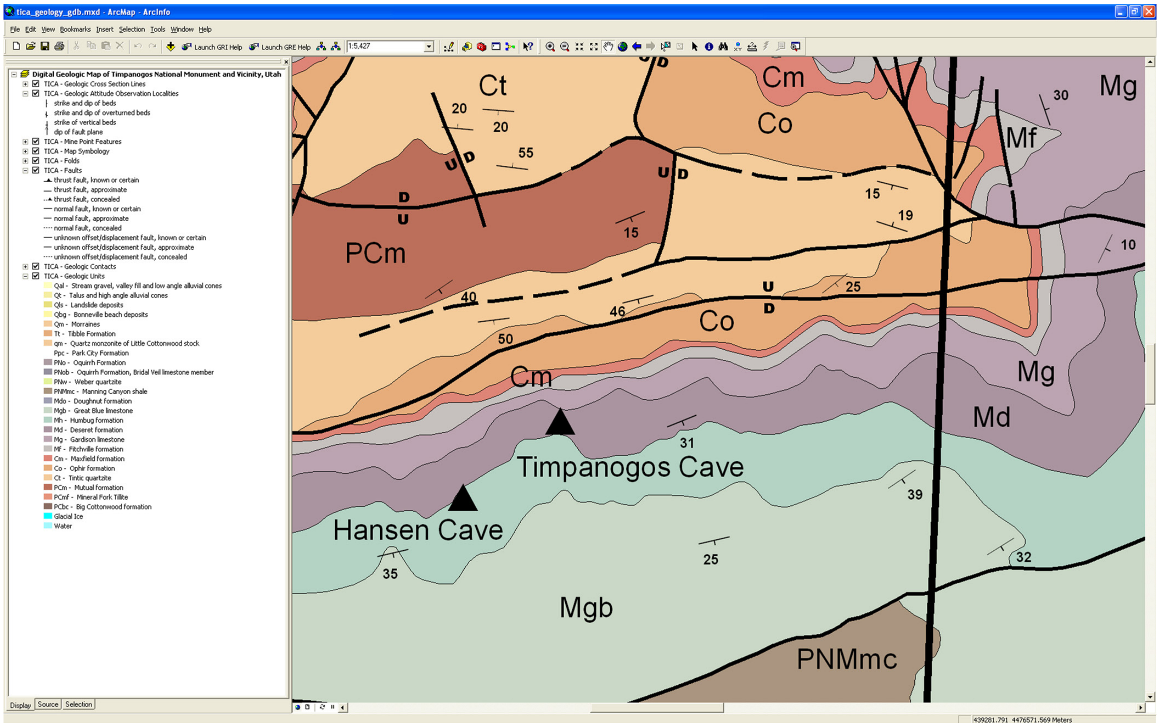

Figure 7. View of the GRI geologic GIS data in American Fork Canyon surrounding Timpanogos Cave National Monument.

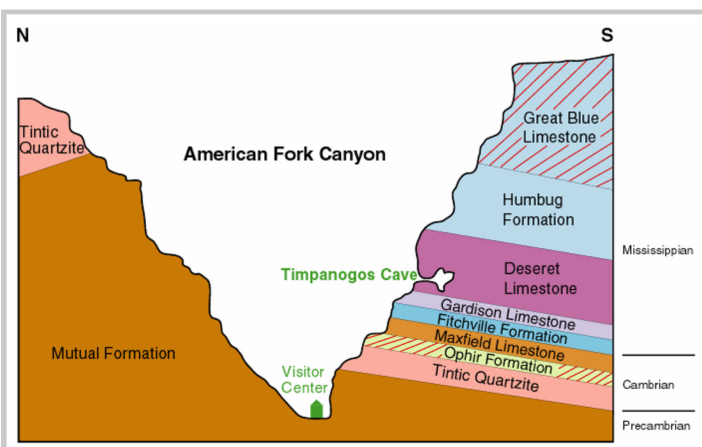

Figure 8. Generalized cross section of American Fork Canyon, including the Timpanogos Cave system (from Timpanogos Geologic Report, adapted from NPS graphic).

Figure 9. Urchin, Chimes Room, Timpanogos Cave National Monument (photograph by NPS).

Additional Information

Additional information is available on the poster presented at the DMT meeting (fig. 10), and at the GRI Web site: *http://www.nature.nps.gov/geology/inventory/*.

For questions about the NPS GRI Program, please contact:
- Bruce Heise (bruce_heise@nps.gov)
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- Heather Stanton (heather_stanton@partner.nps.gov)
- James Chappell (jim_chappell@partner.nps.gov)

For questions about the availability of GRI digital data, please contact:
- Stephanie O'Meara (stephanie.omeara@colostate.edu)
- Tim Connors (tim_connors@nps.gov)

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O'Meara, S.A., Stanton, H.I., and Chappell, J.R., with contributions from Mack, G., Hybels, G., Karpilo, R.D., and Croskrey, A., 2008, National Park Service Geologic Resources Inventory Geology-GIS Geodatabase Data Model (v. 2.1): Colorado State University and National Park Service, 95 p., *http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.htm*.

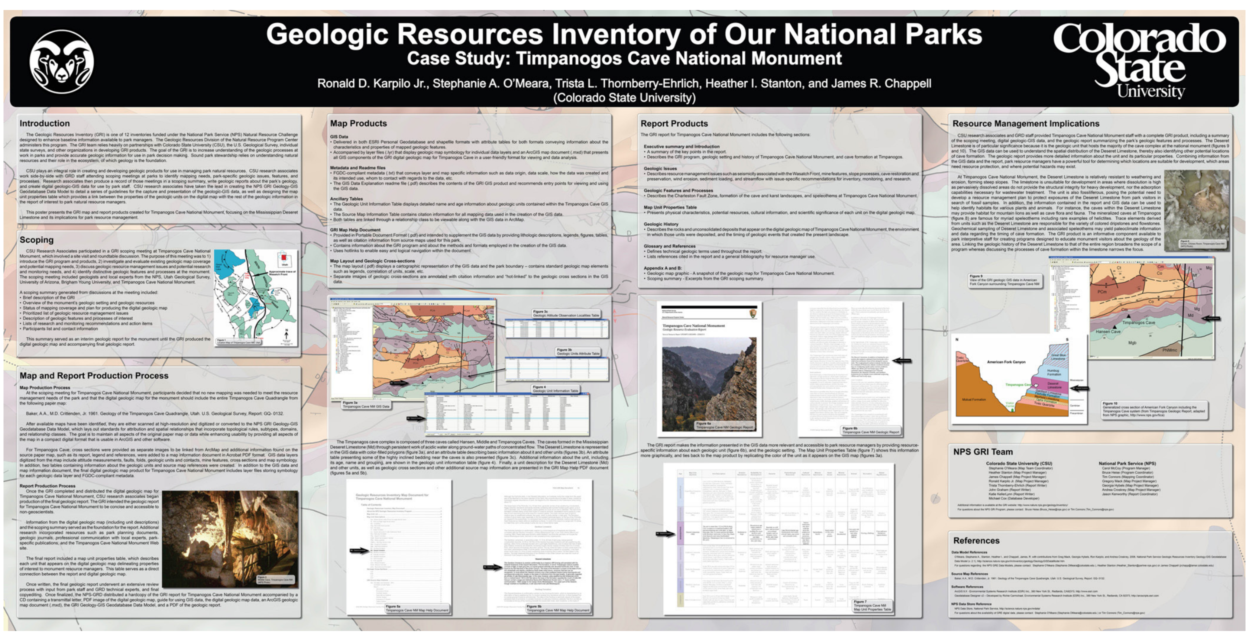

Figure 10. Poster titled "Geologic Resources Inventory of Our National Parks, Case Study: TICA," presented at the Digital Mapping Techniques 2009 workshop in Morgantown, WV. A high-resolution version of this poster is available for download at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Karpilo.pdf*

Overcoming Cartographic and Technical Challenges in Developing an Interactive Mapping System for the Appalachian Basin Tight Gas Reservoirs Project

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Objectives of the Appalachian Basin Tight Gas Reservoirs Project

A major objective of the Appalachian Basin Tight Gas Reservoirs Project (ATG; *http://www.wvgs.wvnet.edu/atg/*) was to design and implement an interactive mapping system (IMS) Web site that consolidates a broad range of information about six main groups of tight gas reservoirs and can be extended to any gas reservoir in the future. Data for this project came from a wide variety of sources; however, the vast majority of the data layers used were converted into GIS format from *The Atlas of Major Appalachian Gas Plays* (Roen and Walker, 1996). This project was supported by U.S. DOE contract DE-FC26-05NT42661.

This objective presented many unique cartographic and technical challenges, which were further complicated by the need to switch the software platform from ESRI's newer ArcIMS© ArcMap Image Server, that uses ArcMap© MXD files to show the maps online, back to the original, older ArcIMS Image Server which uses maps rendered in AXL code, for final implementation of the Web site. Initially, ArcGIS Server was considered for the project; however, at the time the mapping application was developed, ArcGIS Server did not meet the needs of the project. The WVGES is planning to migrate the system to ArcGIS Server in the future.

Color Coding the Play-Based Layers: We Found the Rainbow Connection

Due to the overwhelming amount of data to be presented as point, line, and polygon based layers for *each* of the six main Tight Gas Plays (260 IMS layers were rendered), it was decided to color code the plays into the main color 'families' that make up the rainbow: Red, Orange, Yellow, Green, Blue/Indigo, and Violet. See available color "families" in the ArcMap color palette in figure 1. This way there would be enough hues and shades within each color group to uniquely symbolize each data layer within the play but still indicate to the viewer that layers were geologically related to each other in the same play because they were of the same general color.

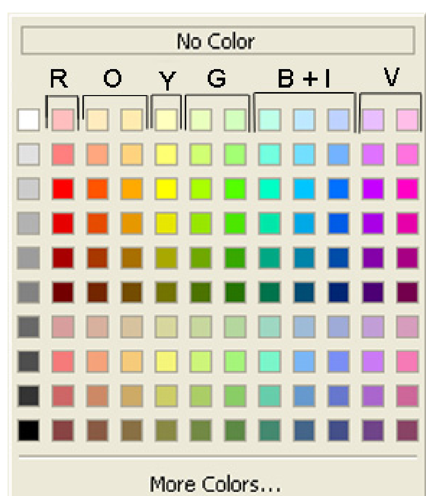

Figure 1. ArcMap Color Palette showing main color "families" available for rendering layers. R=red, O=orange, Y=yellow, G=green, B+I=blue/indigo, and V=violet.

Also, since it was expected that the viewer might wish to mix and match the data from different plays together in the display to make comparisons, it was important to be able to distinguish similar-looking data layers that were repeated in each play, such as isopach lines or gas field polygons, as belonging to the same or different plays.

The play with the fewest data layers, the Medina/"Clinton", was assigned yellow since it is the color with the fewest discernible shades (fig. 2). The play with the most layers, the Elk (fig. 3), was assigned the combined color families of blue and indigo, since these colors had the most hues from which to choose for cartographic rendering. The other plays (Berea, Venango, Bradford, and Tuscarora) were assigned to their respective color families for similar reasons (figs. 4 through 7).

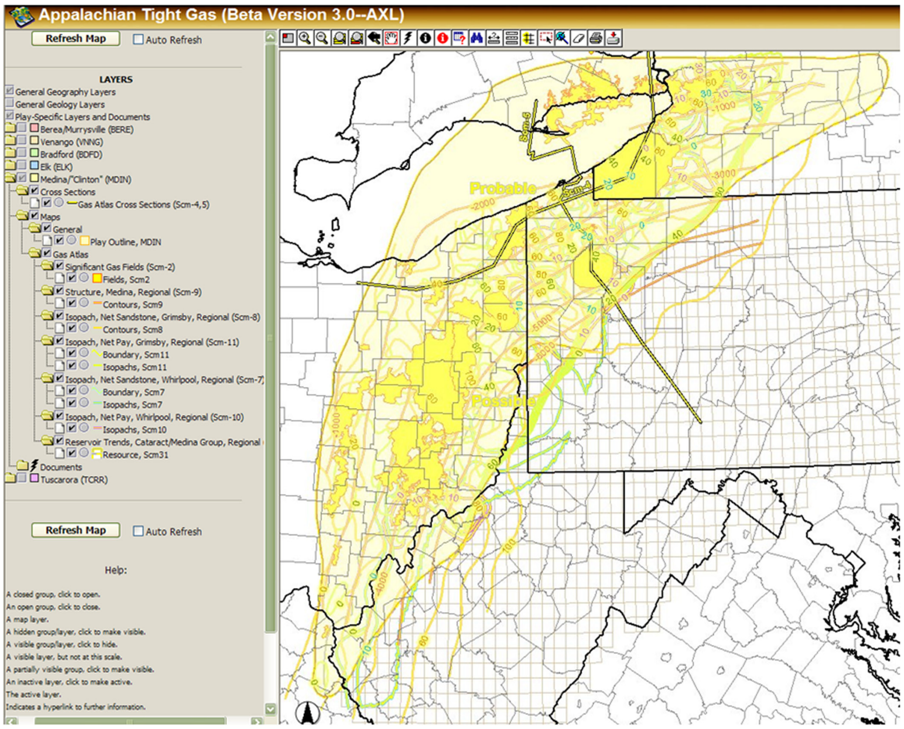

Figure 2. The Medina/"Clinton" Play of the ATG IMS contains 11 data layers and was assigned colors in the yellow family.

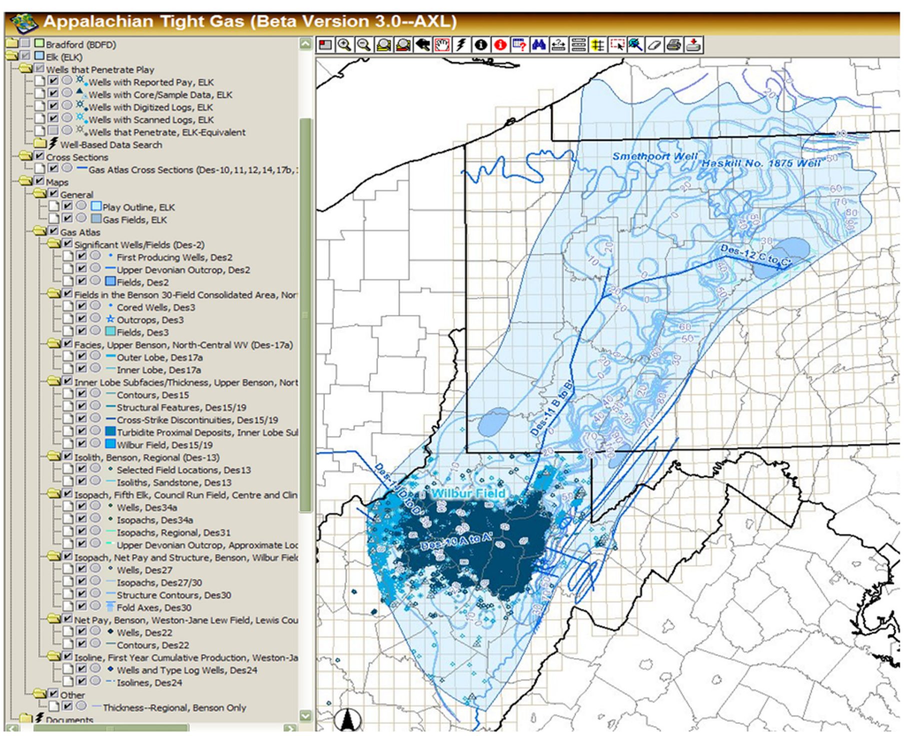

Figure 3. The Elk Play of the ATG IMS contains 36 data layers and was assigned blue and indigo colors.

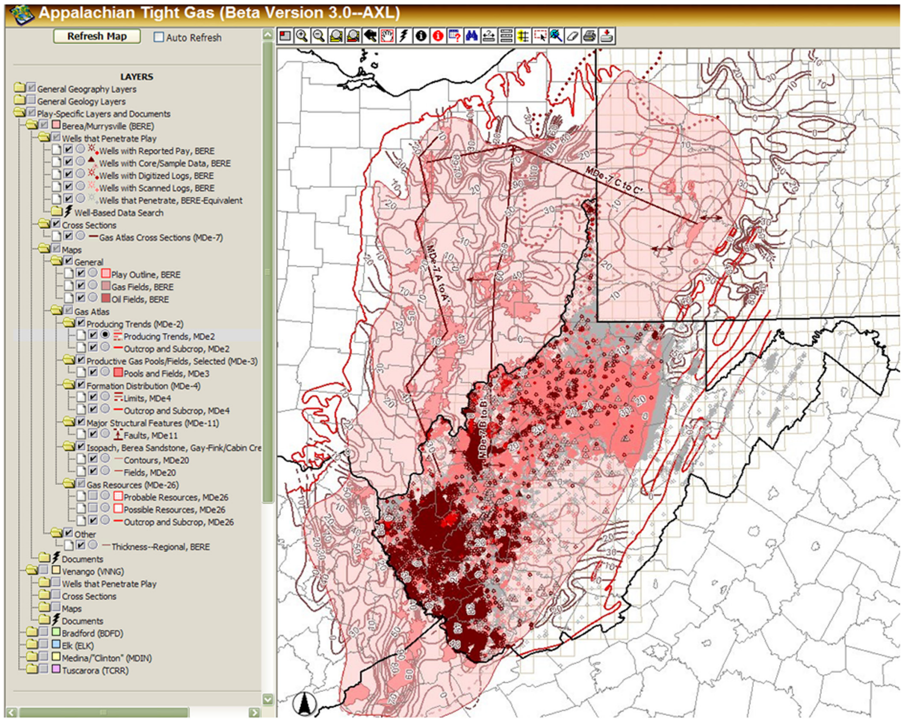

Figure 4. The Berea Play of the ATG IMS contains 21 data layers and was assigned red colors.

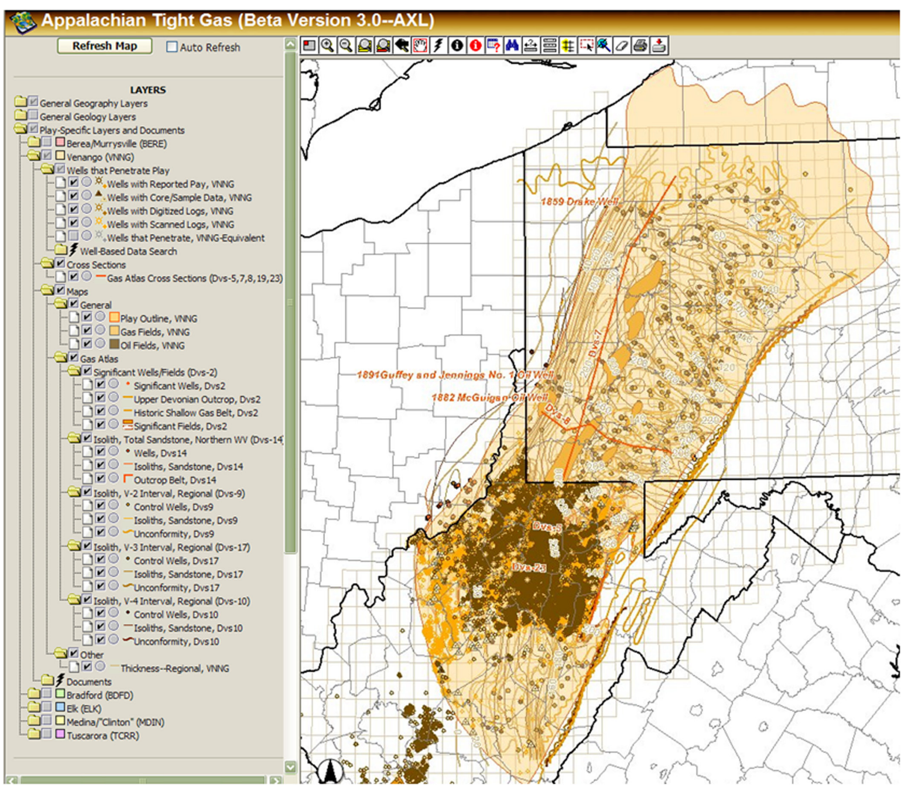

Figure 5. The Venango Play of the ATG IMS contains 26 data layers and was assigned orange colors.

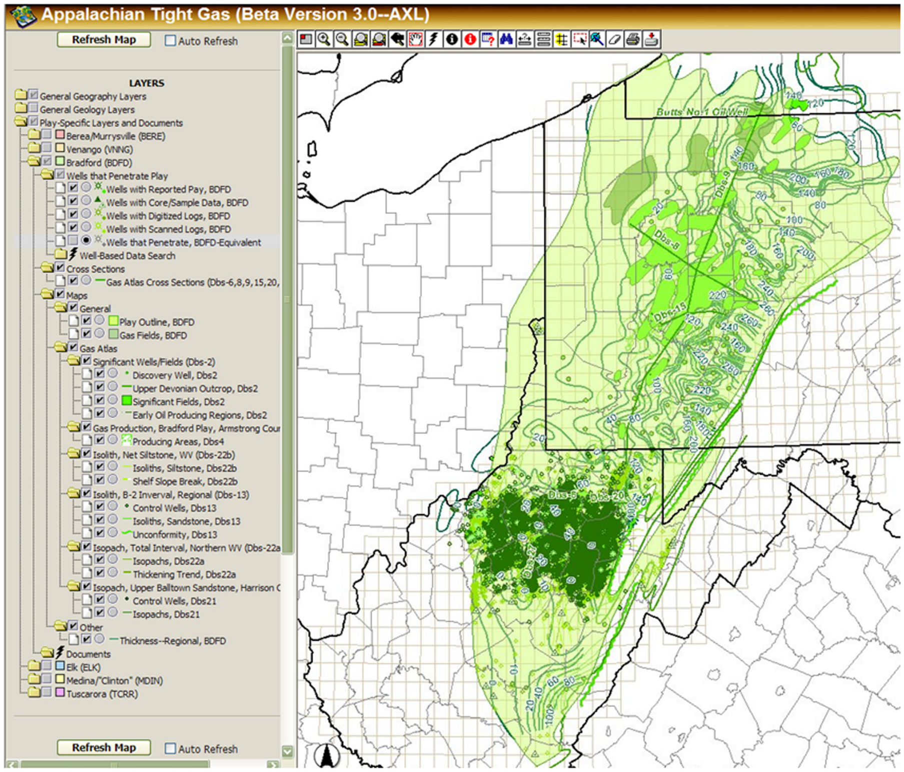

Figure 6. The Bradford Play of the ATG IMS contains 23 data layers and was assigned green colors.

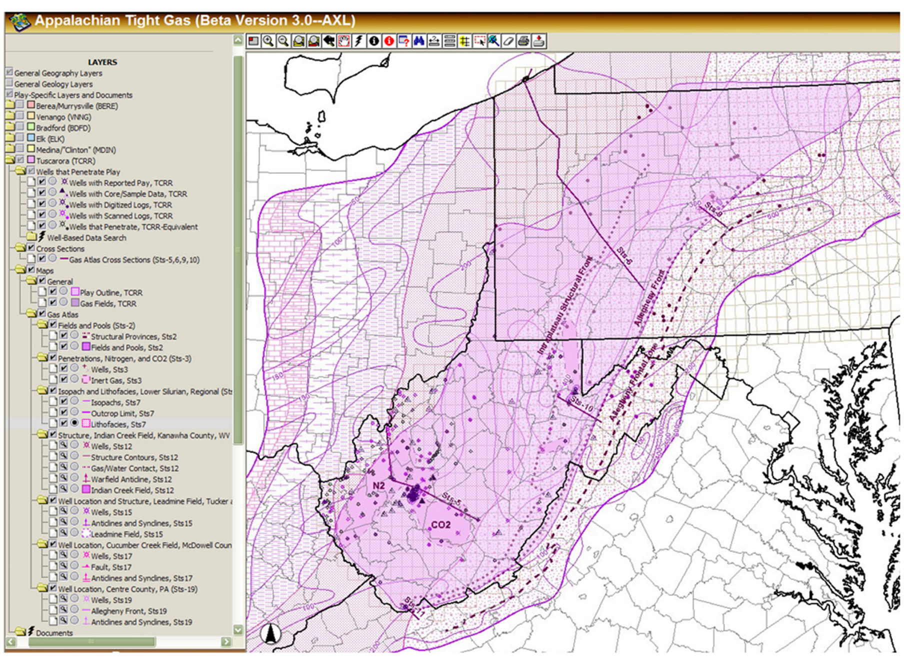

Figure 7. The Tuscarora Play of the ATG IMS contains 29 data layers and was assigned violet colors.

Form Versus Function

Functional Differences Between the Two Versions of ArcIMS: AXL-Based Versus MXD-Based

There were several important functional advantages to be gained by switching the IMS platform to the original ArcIMS Image Server.

Overall speed was vastly improved, as shown in the "Speed Comparison Table" (table 1). The entire application was more stable and robust, in that the interactive maps will still function should one or more layers become unavailable in the AXL version, whereas this would cause the MXD version of the application to crash. A summary of main differences between the two versions of IMS, showing positives and negatives for each version, is shown in table 2.

The ability to use the buffer tool to select and buffer features from the same layer in order to perform data queries and display information was considered a vitally important function of this IMS application (fig. 8). In the WVGES' other oil and gas applications, users commonly employ these tools to select, query, and extract data subsets from well point layers.

Scale-dependent rendering of data layers, particularly well point symbols, was advantageous in this Web application due to the sheer number of well points and well point data layers. At large scales, a smaller point symbol is shown, and as the user zooms in, the detailed well type information appears as the point symbol gets larger and the point label appears.

Metrics of Table 1:

The MXD (ATG2) and AXL (ATG_AXL) versions of the ATG IMS application exist on the same IMS server at WVGES. Five trials were done using the Firefox browser for each version on a laptop computer (see computer specs, below) via a wireless connection in Morgantown, WV. Table 1 shows the averages of those trials with times in seconds. The Firebug tool provided a means to measure the elapsed time for feature downloads. A "real feel" time using a watch was also taken—from the moment the "enter" key is pressed to when the eye sees the finished view loaded into the browser window.

Simple and standard IMS tools were used for the metrics: loading of single or multiple layers at once and then zooming to varied extents. The selection of "adding all layers" at once provided maximum stress to both server and client machines. The MXD (ATG2) version failed at this point, timing out at 2 ½ minutes (150 seconds) after the attempted load. This point of time-out was used to calculate values for the "all layers" test and for the "zoom to Morgantown" test.

Performance of the AXL-based application was far superior to the MXD version. Although it took time and effort to construct the 4,600+ lines of AXL code, the results justified the investment for this large (260+) layer IMS application. The ATG_AXL application is available at *http://www.wvgs.wvnet.edu/atg/*; the ATG2 version is no longer available.

Specifications of the client machine (laptop): Acer Aspire 4730z; MS Windows Vista, SP1; 3 GB RAM; Processor - Intel(R) Pentium(R) Dual CPU T3400 @ 2.16GHz: L2 cache 32 Kbx2; Video - Mobile Intel(R) 4 Series Express Chipset Family, 1309 MB total available graphics memory; Wireless - b/g/n, Ralink 802.11n wireless LAN card; Setting - Other than MS Paint, Firefox was the only directly user-called program running on the client system; access was via a Morgantown wireless "hotspot" (avg. 11megabit/s).

Table 1. Speed comparison of AXL and MXD versions of ATG IMS.

Numbers are averages of 5 trials for each version.

	ATG_AXL (AXL)			ATG2 (MXD)			AXL (ATG_AXL) is faster than MXD (ATG2) by:				
Task	Firebug (s)	Real Feel (s)	Difference (s)	Firebug (s)	Real Feel (s)	Difference (s)	Firebug (s)	Real Feel (s)	Difference (s)	Firebug (s)	Real Feel (s)
Initial open	14.47	16	1.93	27.85	29	1.15	**13.39**	**12.60**	**-0.79**	**48.06%**	**43.45%**
Zoom to the city of Morgantown	1.32	1	-0.52	15.28	17	1.32	**13.96**	**15.80**	**1.84**	**91.35%**	**95.18%**
Add All Oil and Gas Wells Layer from General Geology	6.44	7	0.56	33.83	34	-0.23	**27.39**	**26.60**	**-0.79**	**80.96%**	**79.17%**
Zoom to Osage quadrangle	2.73	3	0.27	20.63	22	1.17	**17.90**	**18.80**	**0.90**	**86.77%**	**86.24%**
Add all layers in General Geology	2.75	3	0.25	20.80	22	1.40	**18.05**	**19.20**	**1.15**	**86.78%**	**86.49%**
Add all layers (everything)	13.43	14	0.37	150.00	150	0.00	**136.57**	**136.20**	**-0.37**	**91.05%**	**90.80%**
Zoom to the city of Morgantown	9.47	10	0.13	150.00	150	0.00	**140.53**	**140.40**	**-0.13**	**93.69%**	**93.60%**

Table 2. Summary of IMS Version Differences

Negatives in red Positives in green	MXD Version ArcMap Image Server	AXL Version ArcIMS Image Server
Speed	Noticeably slow	Significantly faster!
Stability	One 'bad' layer will crash whole IMS	Robust: if >= one layer unavailable, it still works
Cartographic capabilities	Full range of ArcMap rendering available	Simple line styles only
Labels	Full range of ArcMap labeling available	Limited labeling capabilities
Buffer tools	Does not function as desired in IMS (buffer and select from same layer)	Fully functional
Scale-dependent rendering	Labels only	Fully functional for both cartography and labels

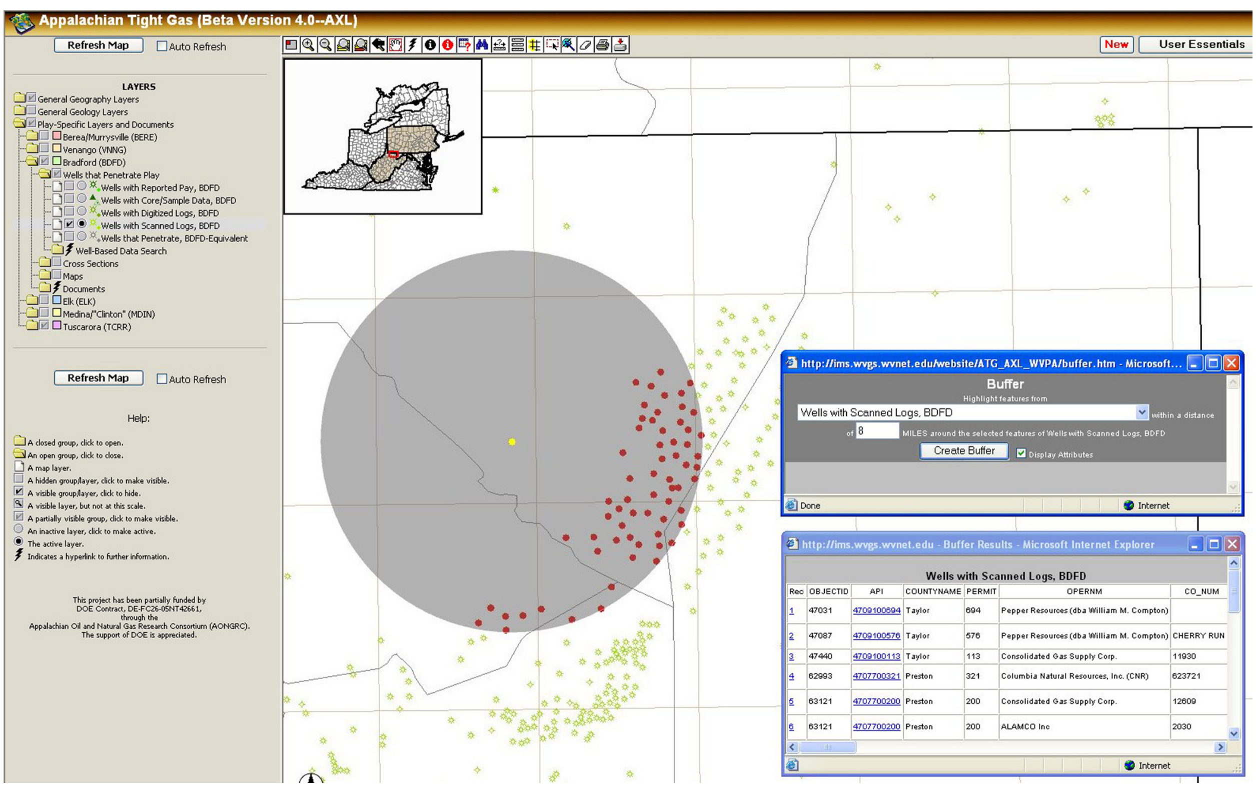

Figure 8. Example of buffer tools. View of Monongalia County, WV, showing a well point (in yellow) selected and buffered to a distance of 8 miles (gray circle) in order to select other well points in the same layer that are of interest to the user (selected points shown in red). The lower pop-up window shows the attributes of the selected wells. For the Bradford Play, the "Wells with Scanned Logs" layer of the ATG IMS is shown.

Cartographic Differences Between the Two Versions of ArcIMS: AXL-Based Versus MXD-Based

The ATG maps were originally rendered in ArcMap and the native MXD files were served to the Web using ESRI's newer ArcIMS ArcMap Image Server. This method allowed the complex cartography required to show the geologic features such as thrust faults, anticlines and synclines, multilayered symbols, and complex labeling of features to be displayed online as originally intended by the cartographer.

Unfortunately, some functions vital to the project, such as the ability to use the buffer tool to select and buffer features from the same layer in order to display information (fig. 8), and the ability to render layers differently dependent on scale, were not available in the ArcIMS ArcMap Image Server version. Thus it was decided to switch the maps to the original ArcIMS Image Server, which uses maps rendered in AXL code, for final implementation of the Web site.

The AXL code cannot symbolize data as elegantly as the MXD file, especially with respect to line symbology, but the advantages of the AXL file functionality far outweighed the cartographic disadvantages (table 2).

Some Specific Examples

Some creative tweaking of AXL code was required in order to emulate some vitally important geologic symbology. Line symbols available in the AXL version were limited to solid, dashed, dot, and various dash-dot combinations. These line styles were insufficient to symbolize geologic features such as thrust faults and fold axes, which usually are shown with line decorations such as arrows for folds and "teeth" for thrust faults (compare the fault lines shown in figures 9 and 10).

It was unacceptable for a geological survey to host a Web site that cannot display common geological symbols, so a method was devised to customize the road layer symbology in the AXL code using the <RASTERSHIELDSYMBOL> tag and to use custom-made 'shield' .gif images of fold arrows to display these symbols (figs. 10 and 12). The custom fold arrow images were created individually in PaintShop Pro© for each fold type (anticline, syncline, overturned anticline, and so on) and also for each fold type in the color group required per Play in the IMS. Then the road layer symbology AXL code was repurposed by replacing the road shield symbol .gif in the code (for Interstates, U.S. Highways, and so on) with the specific fold arrow symbol required for each individual

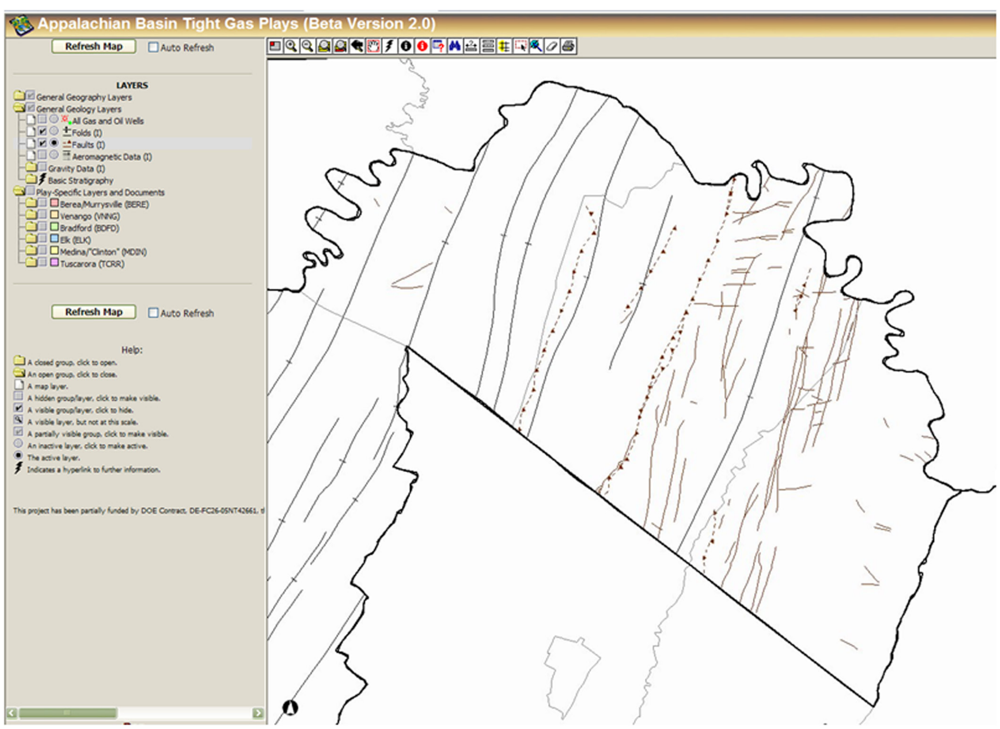

Figure 9. "Before" – lines in the MXD version: view of the Eastern Panhandle of West Virginia showing the "General Geology Folds and Faults" layers of the ATG IMS symbolized with the standard geological line symbols for fold axes and thrust faults available from the ArcMap symbol palette.

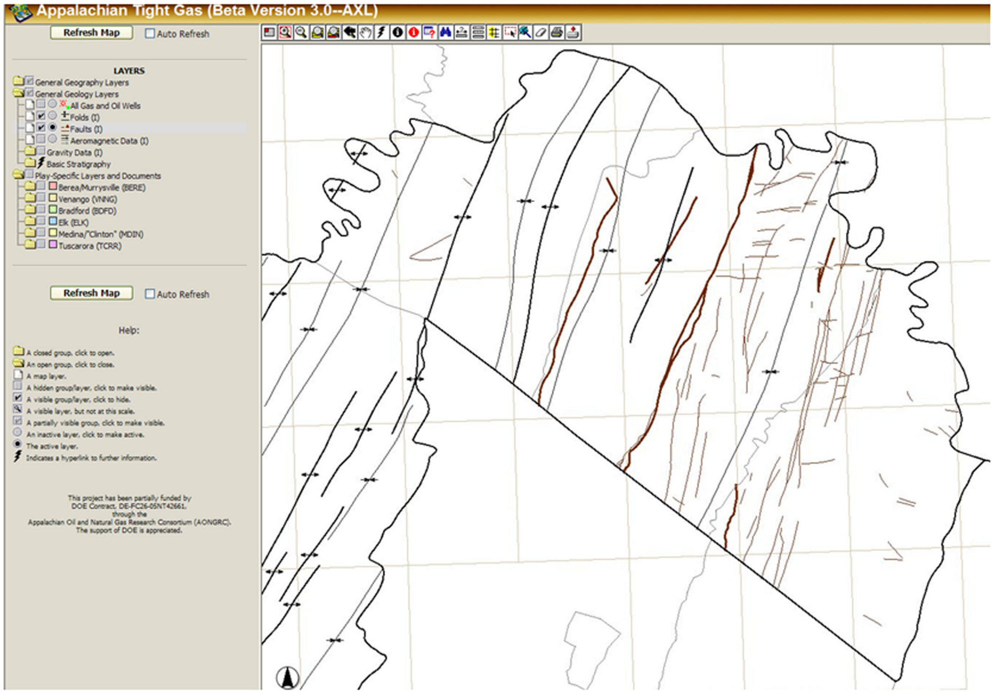

Figure 10. "After" – lines in the AXL version: same view as in figure 9, showing the fold axes symbolized with the customized <RASTERSHIELDSYMBOL> tag and thrust faults symbolized with thick/thin line styles. Note how the custom .gif image of the fold arrows cannot be rotated relative to the fold axis line, remaining horizontal relative to the screen.

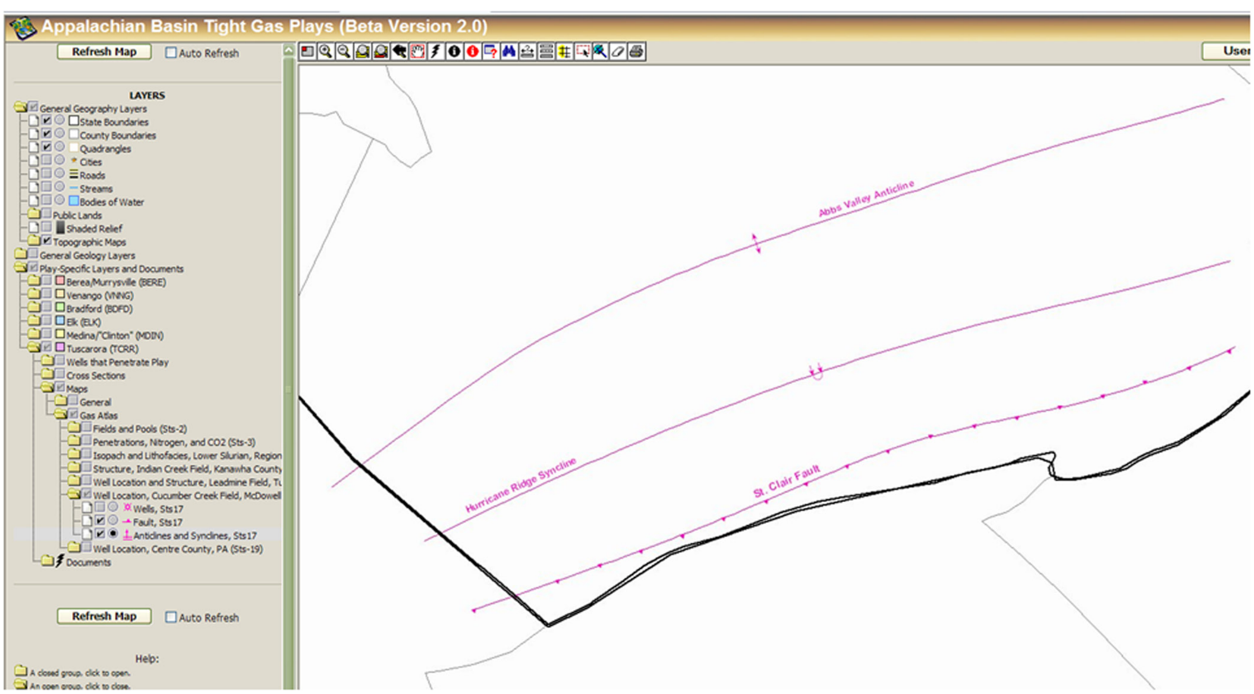

Figure 11. "Before" – line decorations in the MXD version: view of Tuscarora Play in Mercer County, WV, showing the standard geological symbols for fold axes and thrust faults available from the ArcMap symbol palette. (Tuscarora Play Fig. Sts-17 layer of the ATG IMS shown.)

layer, as the following examples show (highlighted in red). The thrust fault line symbology could not readily be modified except by using a thick, solid line style (fig. 10), but at least the fold axes could be properly symbolized for the Web. However, the rotation of the fold axis symbol relative to the fold line could not be controlled, and so the symbol remains horizontal to the page/screen, not perpendicular to the fold line as it should be (compare figures 11 and 12).

AXL code for customized use of the <RASTERSHIELDSYMBOL> tag and specially created fold-arrow .gif images applied to the fold layer produced the symbols shown in figure 10. The following example shows a generic anticline and syncline fold symbol used in the “General Geology” IMS Layer:

```
<VALUEMAPLABELRENDERER lookupfield=”Type”
labelfield=”Type” linelabelposition=”placeontophorizontal”>
  <EXACT value=”Anticline” label=”Anticline”>
     <RASTERSHIELDSYMBOL font=”Arial” fontcolor=“0,0,0”
         fontsize=”1” image=”anticline_general2.gif”
         transparency=”1”/>
  </EXACT>
  <EXACT value=“syncline” label=”Syncline”>
     <RASTERSHIELDSYMBOL font=”Arial” fontcolor=“0,0,0”
         fontsize=”1” image=”syncline_general2.gif”
         transparency=”1”/>
  </EXACT>
</VALUEMAPLABELRENDERER>
```

The following AXL code for customized use of the <RASTERSHIELDSYMBOL> tag and specially created fold-arrow .gif images was applied to “Tuscarora Play” fold layers in figure 12. This example uses the fold arrow symbols that had to be uniquely created in the Tuscarora Play color (purple shades) and also for an overturned fold:

```
<VALUEMAPLABELRENDERER lookupfield=”TrendName”
labelfield=”TrendName” linelabelposition=”placeontophorizontal”>
  <EXACT value=”Anticline” label=”Anticline”method=”IsContained”>
     <RASTERSHIELDSYMBOL font=”Arial”
         fontcolor=”255,0,197” fontsize=”1”
         image=”anticline_Sts17.gif” transparency=”1”/>
  </EXACT>
  <EXACT value=”Syncline” label=”Syncline”method=”IsContained”>
     <RASTERSHIELDSYMBOL font=”Arial”
         fontcolor=”255,0,197” fontsize=”1”
         image=”overturnedsyncline_Sts17.gif”  transparency=”1”/>
  </EXACT>
</VALUEMAPLABELRENDERER>
```

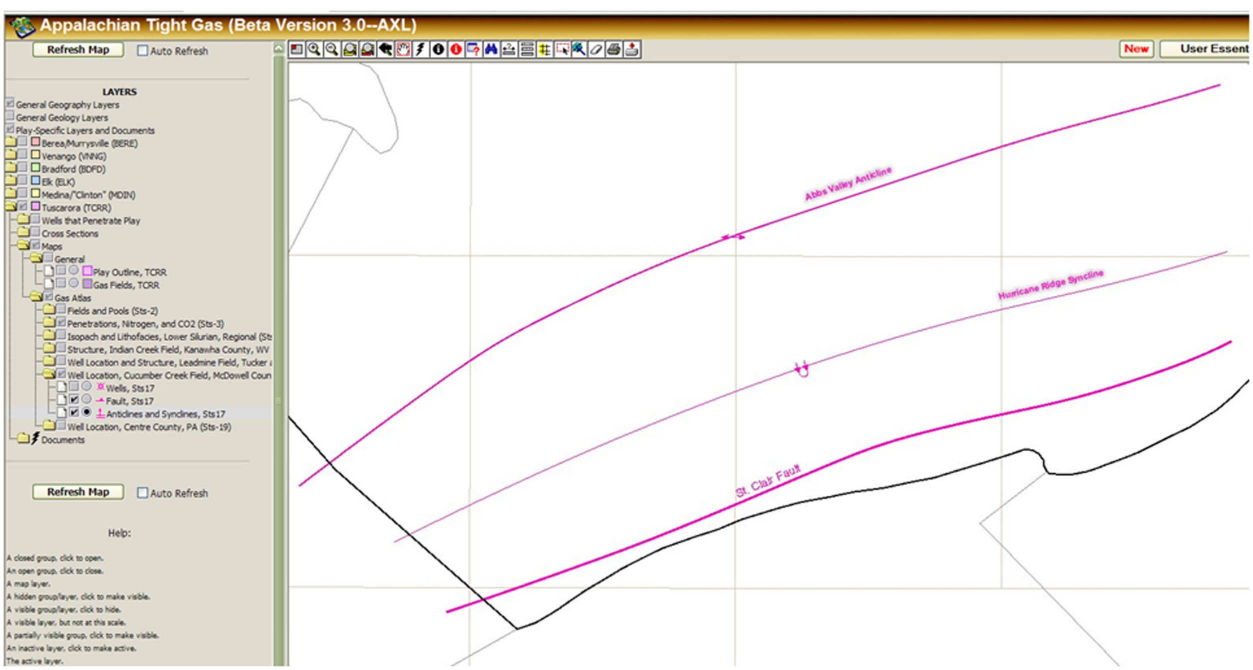

Figure 12. “After” – line decorations in the AXL version: same view as in Figure 11, showing the fold axes symbolized with the customized <RASTERSHIELDSYMBOL> tag and thrust fault symbolized with thick, solid line style. Note how the custom .gif image of the fold arrows cannot be rotated relative to the fold axis line, remaining horizontal relative to the screen.

Some of the more complex and creative labeling that ArcMap is capable of serving to the Web in the MXD version unfortunately had to be sacrificed for the final AXL-based version of the IMS. For example, superscripts and subscripts are not supported by the AXL code, so inert gases such as carbon dioxide and nitrogen cannot be correctly scientifically labeled (compare figures 13 and 14) which, for an internet application publishing scientific data, is obviously not ideal.

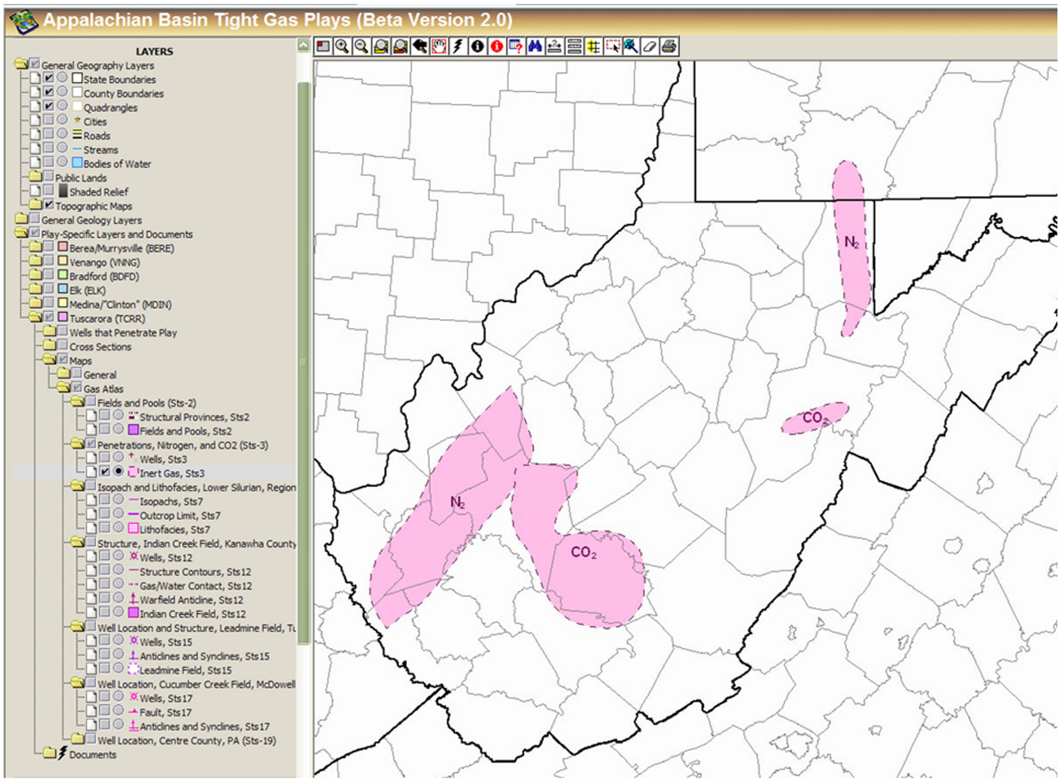

Figure 13. "Before" – the MXD version: view of WV showing some of the complex labeling options available in ArcMap and applied to the Tuscarora Play (Fig. Sts-3 layer of the ATG IMS shown). The inert gas fields are correctly scientifically labeled using subscripts.

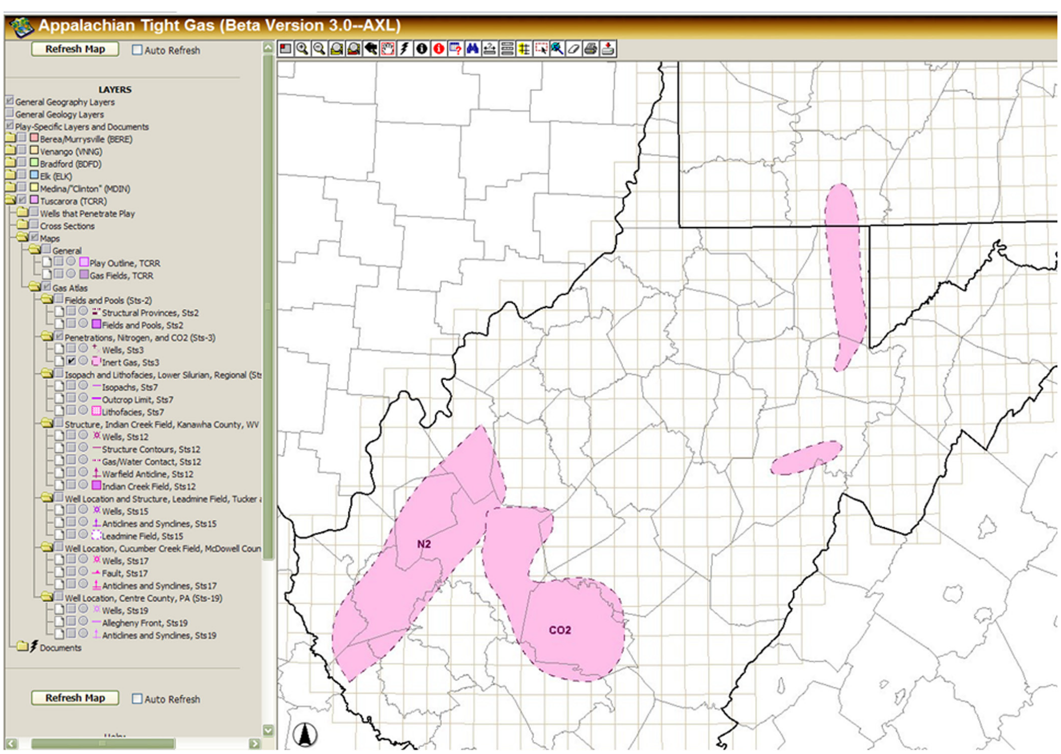

Figure 14. "After" – the AXL version: same view as in figure 13. Subscripts and superscripts are not supported in the AXL code.

Layered labels (labeling a feature with more than one label at a time using two or more attribute fields) and label classes that define and uniquely label different features based on attributes also are not supported in AXL code. Nor are specialized label placement functions such as defining label offset from its line feature, or the ability to control its placement and (or) orientation to the line (compare the "Rome Trough" label in figures 15 and 16).

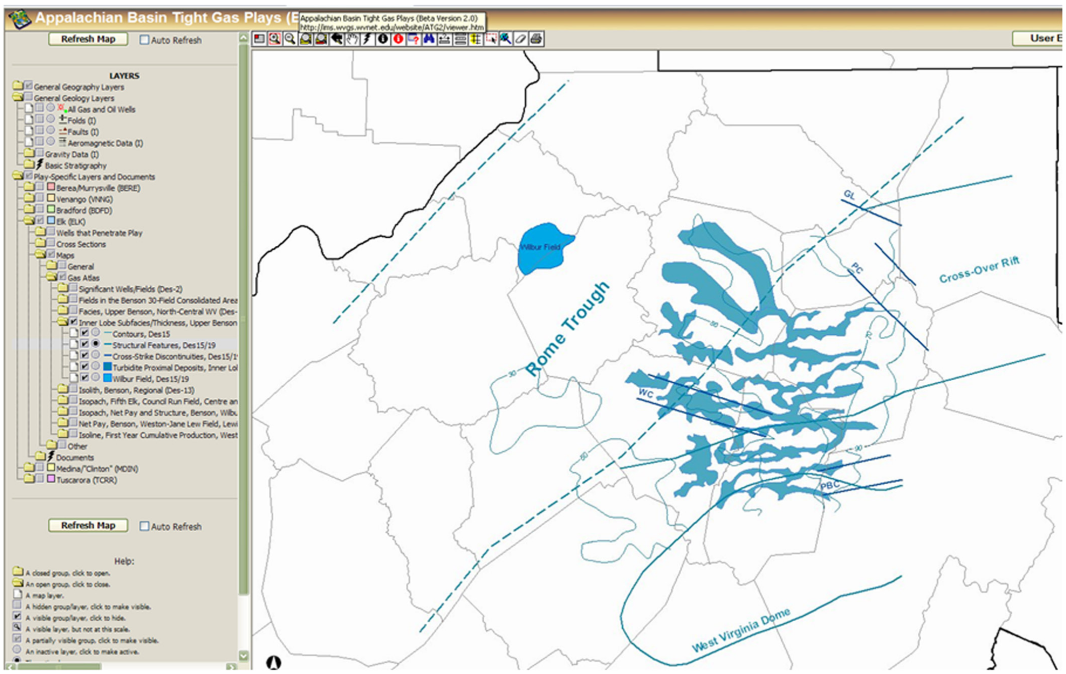

Figure 15. "Before" – the MXD version: view of West Virginia showing some of the complex labeling options available in ArcMap. The structural features are labeled differently based on attribute classes, and specialized label placement and orientation is employed, e.g. "Rome Trough" label. (Elk Play Fig. Des-15/19 layer of the ATG IMS shown.)

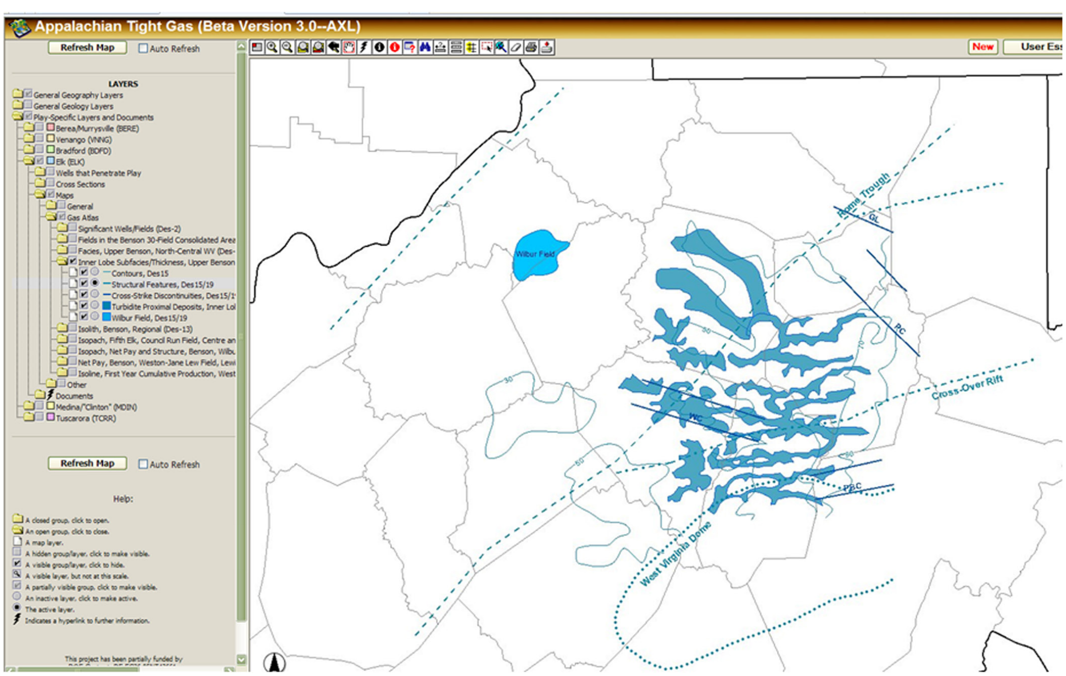

Figure 16. "After" – the AXL version: same view as in figure 15, showing examples of the limited labeling options that are supported in the AXL code.

ArcMap includes the capability to symbolize lines that include decorations (for example, fault teeth) and to use graphic elements to create complex line styles. For example, lines for regional unconformities can be rendered with the standard geologic "squiggly" line style using an "S"-shaped graphic element. In figure 17, the outcrop belt is shown with a hachured line style, but the lines themselves (with one exception) were digitized as straight lines. To show the unconformity lines in the AXL version, which cannot support complex line styles, the lines had to be completely redigitized as "squiggles" (fig. 18) and the outcrop belt had to be symbolized as a plain, straight line.

A page-sized version of the poster presented at DMT'09 is shown in figure 19. A full-resolution image can be viewed online at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Gooding.pdf*.

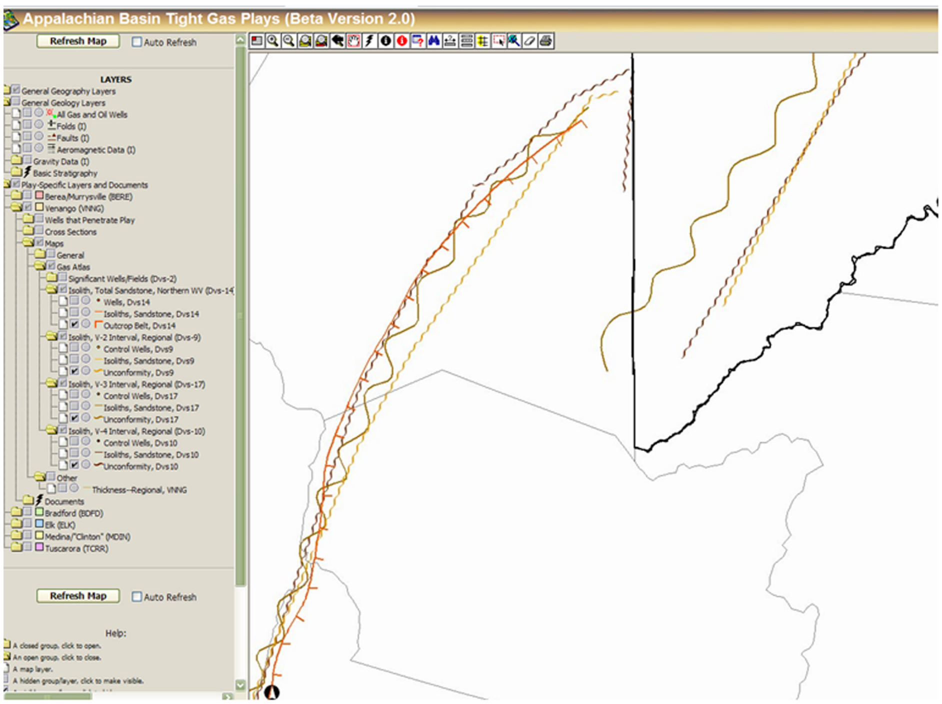

Figure 17. "Before" – the MXD version: view of Preston County, WV, showing some of the complex line rendering options available in ArcMap. The unconformities are symbolized (with one exception) using an "S" shaped graphic element to mimic the standard geologic symbol. The outcrop belt (in orange) was symbolized with a hachured line style. (Venango Play Figs. Dvs-9, -10, -14 and -17 layers of the ATG IMS shown.)

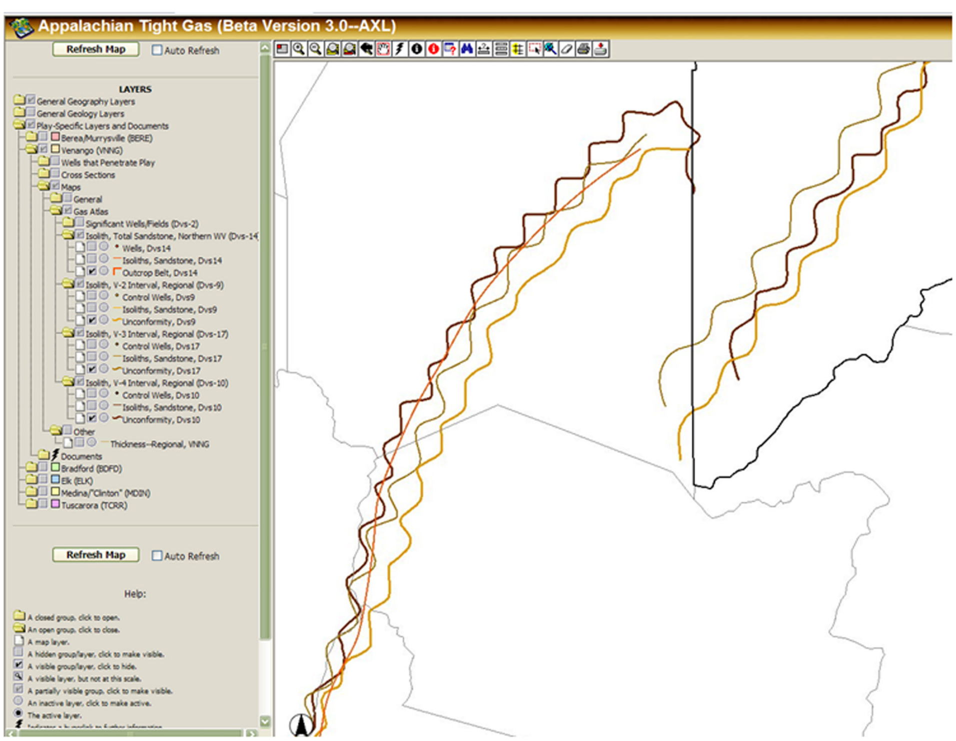

Figure 18. "After" – the AXL version: same view as in Figure 17, showing the lines completely redigitized as "squiggles" in order to properly symbolize the regional unconformities. The outcrop belt (in orange) had to be shown with a plain, straight-line style.

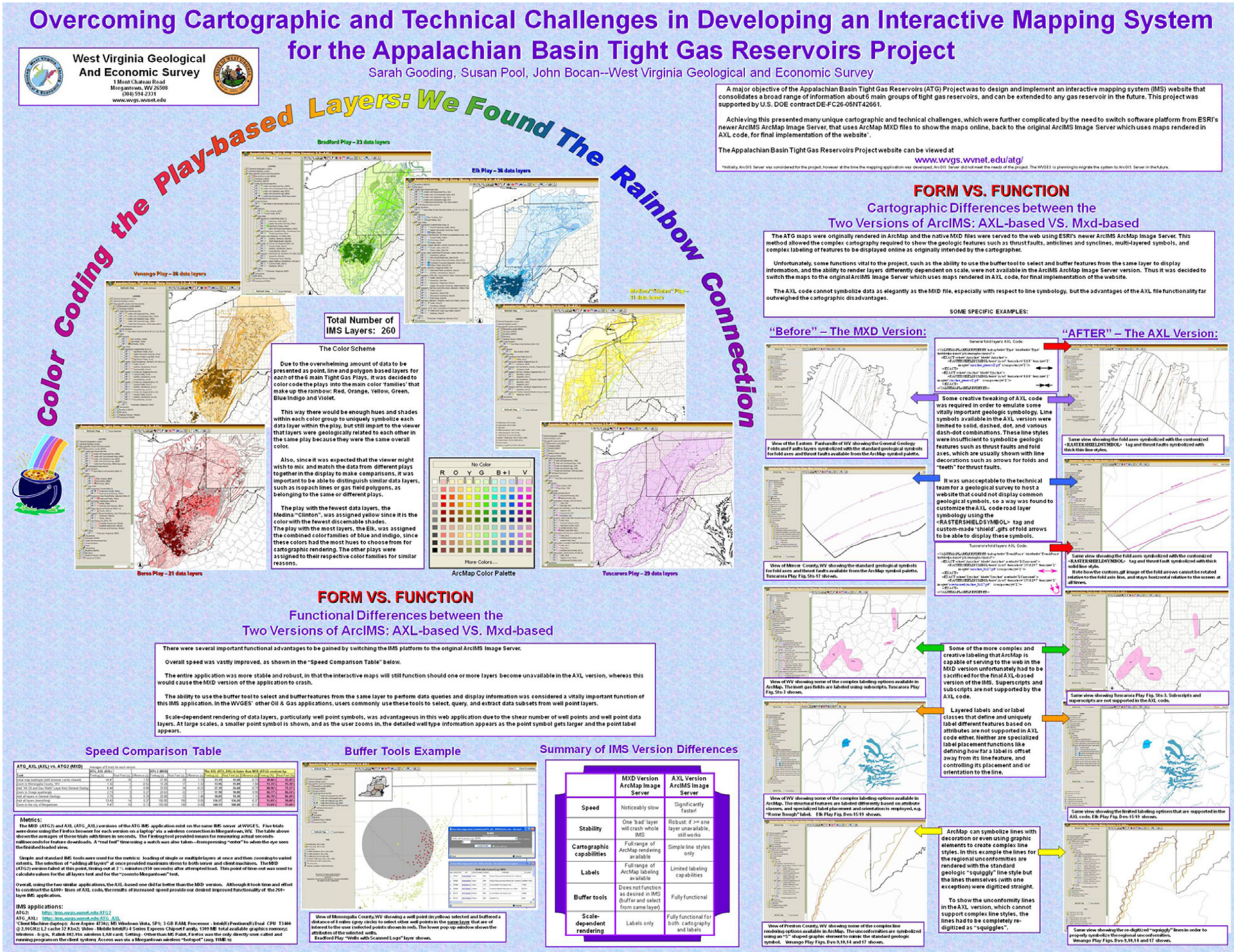

Figure 19. Overcoming Cartographic and Technical Challenges in Developing an Interactive Mapping System for the Appalachian Basin Tight Gas Reservoirs Project (presented as a poster).

Reference

Roen, J.B. and B.J. Walker, eds., 1996, The atlas of major Appalachian gas plays: Morgantown, WV, West Virginia Geological and Economic Survey.

BeeGIS: A New Open-Source and Multiplatform Mobile GIS

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Abstract

Following the release of the MAP IT field data-collection software, a new open-source and multiplatform software has been developed in order to conduct fieldwork in an easier and more intuitive way. This software, BeeGIS, has been designed to work with a Tablet PC, GPS, and digital camera, using a pen on the tablet screen to draw annotations and sketches on the digital map and to connect notes, pictures, and any other files.

A lightweight solution, GeoPaparazzi, has also been developed by exploiting the functionalities of the new Android mobile phones. This software can be easily synched with BeeGIS to import into a GIS or also in Google Earth the captured data (notes, pictures) with attributes (GPS position and orientation).

Introduction

BeeGIS is a new open-source GIS software for field mapping conceived for pen computer working with any common operating system (Windows XP and Vista, Mac OS, Linux). This software was designed to create an efficient and user friendly tool for professionals (mainly geologists and engineers) who may have a limited knowledge of GIS and who want to minimize the learning time for new technologies (Brown and Sprinkel, 2008).

After an unsatisfactory previous experience with design and release of MAP IT (De Donatis and others, 2005; De Donatis and Bruciatelli, 2006), which was developed in collaboration with a commercial software house, our lab (LINEE - Laboratory of Information Technology for Earth and Environmental Sciences) decided to focus our research on open-source software products. From the collaboration between LINEE and HydroloGIS, an environmental engineering company with extensive experience in Java-based GIS development, a new open-source system for geological mapping was developed. During the last year, ARPA Piemonte (a regional Agency for Environmental Protection) supported this project.

Developed in Java (Eclipse platform) BeeGIS has its roots in the Udig framework (open source). In this system, several new tools were designed *ad hoc* for integrated field work; these tools are for:

- data acquisition from any NMEA-compliant GPS receiver for capturing points, lines, and polygons in both automatic and manual mode;
- drawing and writing annotations directly on the map with a stylus, owing to the digital-ink technology that allows you to draw and paint;
- Geonotes: a tool conceived to draw sketches, write text notes, and attach any kind of file, with the ease of drag-and-drop. Digital pictures, once embedded, can be enriched with on-image annotations;
- Fieldbook: the organizer of Geonotes. Like a real field book, it can store, manage, and search all the information captured.

These tools were developed for field usage in order to preserve the traditional methods for mapping, while replacing the pencil and the paper (map and field book) with a digital stylus and touch-screen. BeeGIS is not only designed to help the user to fully support his/her data acquisition, as he would do with traditional tools, it also can drastically reduce the loss of information and time by immediately gathering and storing information just on site and keeping data immediately sharable.

GPS

BeeGIS can be linked to any GPS receiver that supports the NMEA standard protocol, using a serial port connection. Standard wired GPS can be connected by physical USB connection, otherwise by means of a virtual serial port it is possible to connect a wireless Bluetooth GPS. After the parameters setting is completed, a window shows the current main GPS information as coordinates, number of GPS sources viewed in the current constellation, speed and direction of movement, HDOP, data quality, UTC time, and so on.

The position of the surveyor is displayed in real time on the map by a square pointer (with an arrow indicating the direction of movement, in the latest versions); this function allows the field geologist to know the exact position even when a good quality base map is not available or when the land reference point is strongly changed, for example, when surveyors work to map river floods after an extreme rainfall event. Coupled with the GPS connection, a set of functionalities is available. Map display can be centered at current coordinates and the position is updated while moving through the field.

BeeGIS lets the user capture points, lines, or polygons for any feature displayed on the map (fig. 1). This can be done by manual or automatic acquisition. In manual mode, the user can choose where to add a node from the current GPS coordinates to the active layer. If the active feature is "point", single units are stored into the current layer, otherwise, for lines or polygons a node is added into the current lines/polygon layer. This function is particularly useful to acquire the precise position of point features such as a photograph, spring, or well.

With automatic acquisition the node will be captured in real time by the GPS unit without any user action. It is possible to acquire different nodes by choosing a minimum spatial distance (in meters) or a time period (in seconds). By means of this function it is possible to draw a boundary or a path with GPS accuracy just by walking along it. Geologists, for example, can acquire a fault, a landslide limit or a scarp, whereas a forest ranger can acquire a hiking trail simply by walking along it.

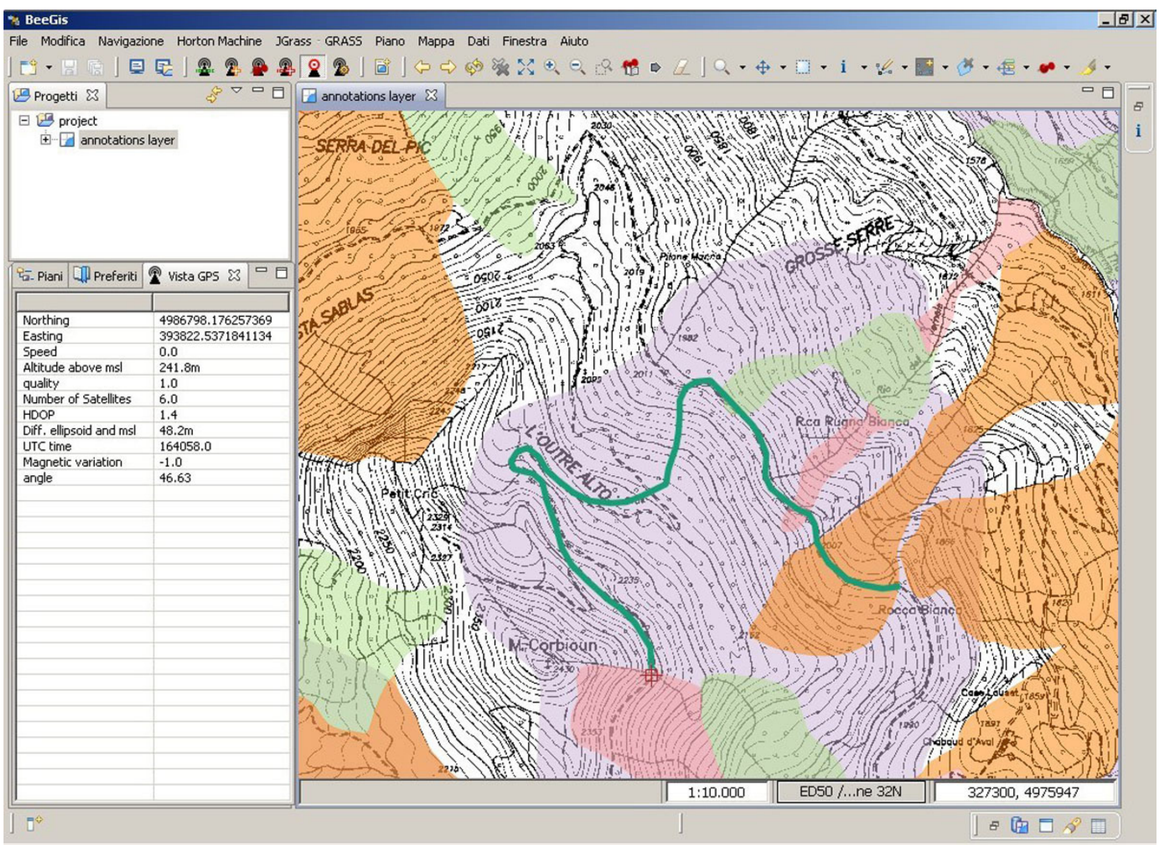

Figure 1. Line (path) captured in BeeGIS using GPS with automatic acquisition.

Geonote and Fieldbook

Another powerful tool of BeeGIS is Geonote. This tool allows the field geologist to add notes on the map in the same way as a sticky-note. All notes are georeferenced and are stored in a specific layer. In the upper part of the Geonote interface, there is a title label field, a few small buttons through which the background color of the note can be changed, and two buttons used to save and close the note or discard it. The lower part of the notes interface shows tabs, where the user can store different kind of data.

The first tab (*drawing tab*) contains freehand drawings and is particularly useful to quickly take notes in the field or to draw sketches with the tablet digital stylus as geologists used to do in the traditional field book.

In the second tab (*text tab*) the user can type notes with the PC keyboard or use the virtual on-screen keyboard on the tablet PC.

The last tab (*media tab*) is a very useful one. It allows users to include any kind of file into the note just by a simple drag-and-drop. These files can be either digital camera images, spreadsheets, or any kind of document the user wants to associate with the subject. All these data are stored together in a database (embedded in BeeGIS) and are readily available. The files can be opened with the default system application for that particular media type just by double clicking on it. When a note is closed, a red pin remains on the map; notes can be viewed by clicking the pin. The note is saved with its coordinates and reference system. This is important because the position is reprojected on the fly in the current view projection system and can therefore be easily used with data stored in other reference systems.

Geonotes are stored in the embedded database and so are not lost when the BeeGIS files are given to a colleague. Moreover, one or more Geonotes can be exported with the dump function in human-readable or binary format. In the first case, BeeGIS creates a new folder containing a set of files: a text info file with position, projection system, names and other useful information, a text file containing the text stored in *textbox tab*, a .png file with the *sketch tab*, and another folder with all linked media file. With the binary dump, all files are stored in a zip file and can be imported to another database or project or can be stored for later use.

For image files, BeeGIS provides an editor that gives the user the opportunity to draw notes on the image with the digital stylus, using different colors, pen thickness, and transparency levels (fig. 2). With a digital camera, users can easily shoot a photo and download it to the tablet PC using a USB cable, a smart-card reader, or a Bluetooth connection (available in some new digital cameras). Making graphical notes on a digital image, while in the field, is very helpful because it allows you to store more complex information than by using the old style field book. For example, a structural geologist can sketch a preliminary interpretation on the outcrop image, or a geomorphologist can fix the main landscape feature on a panoramic view.

In order to easily manage the Geonotes, BeeGIS introduced the Fieldbook browser (fig. 3; see also Briner and others, 1999). Users can search by text in the title, by Geonote color, by creation date, or by whether the observation was located with GPS. The filtered Geonotes can be selected and highlighted, and the map display can be centered at the selected Geonote position.

Picture Georeferencing and Synch

On a survey it is important to be able to connect the measurements and observational data with pictures taken during the field work, particularly in the postprocessing of the collected data. One of the BeeGIS aims is the reduction of postprocessing work, in order to limit the possibility of errors in transcription, redigitalization, and interpretation.

BeeGIS provides a tool to synchronize digital camera pictures with the internal GPS log. In this tool, the picture's timestamp is compared with the internal GPS log points and the position of the nearest GPS point by timestamp is identified; a new Geonote is then created, containing the picture in the Geonote *media box*.

Pictures without matching GPS points are ignored: at the end of the import process, a list of pictures not imported is shown to the user to help verify if the import has been successful.

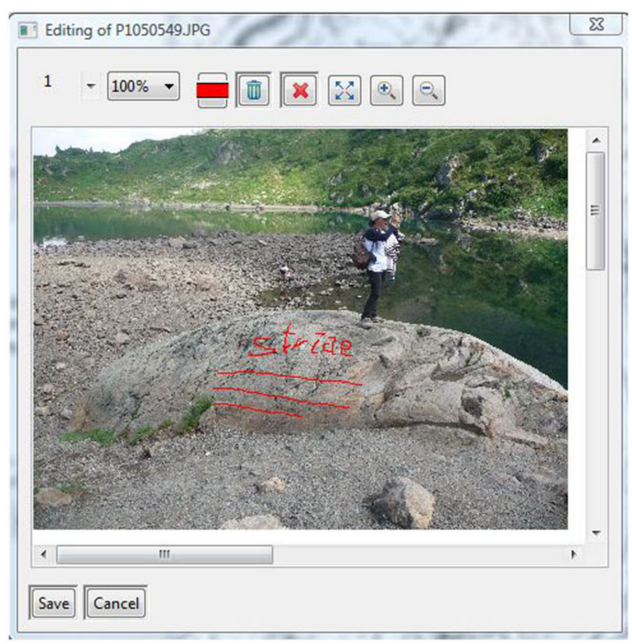

Figure 2. Example images and notes in BeeGIS's Image viewer and editor.

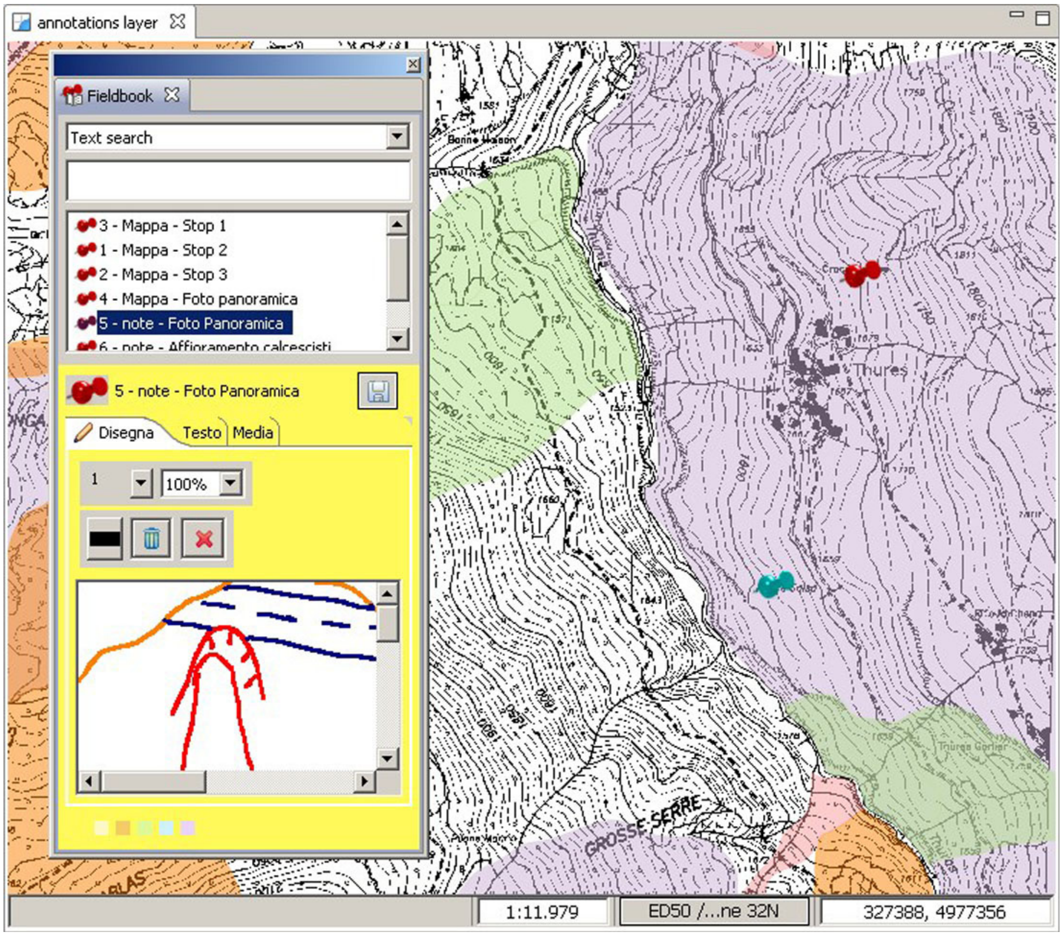

Figure 3. The Fieldbook tool allows the geologist to easily collect the Geonotes.

Annotation Tool

The Annotation tool allows sketches to be drawn directly on the map, as geologists used to do on the traditional paper map using colored pencils (fig. 4). Annotation properties can be chosen as colors, whereas width and transparency can be chosen from drop-down menus or dialog windows.

Unlike traditional paper maps, BeeGIS offers the chance to quickly and easily delete the inserted stroke, by means of the rubber tool; moreover, users can sketch on the map at different scales, so the precision of the strokes can be dramatically improved.

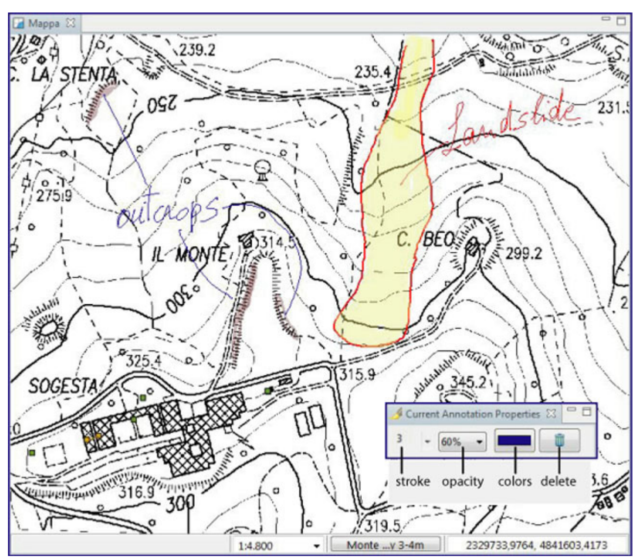

Figure 4. Using the Annotation tool to add field notes to the map.

Synch with Geopaparazzi: Photo and Data Capturing Tool for Android Mobile Phone

Having experienced that sometimes a lightweight and handy tool can be the best solution for capturing data and information in the field (Clegg and others, 2006), GeoPaparazzi was created in order to:

- provide a field tool that fits in any pocket and is always at hand, when needed;
- give the possibility to take georeferenced and possibly oriented pictures during the survey and to import them into the main GIS application BeeGIS (fig. 5);
- use an Internet connection, if available; and
- provide a simple, intuitive tool, with just a few important functionalities.

The main features available in GeoPaparazzi are:

- a map view for navigation (by downloading Open Street Map or, if online, accessing Google Maps);
- georeferenced notes (using GPS functionalities);
- georeferenced and oriented pictures (using GPS, compass and gravity-sensor functionalities);
- GPS logging; and
- easy export of collected data (into BeeGIS or Google Earth).

Figure 5. GeoPaparazzi in Android mobile phone synched with BeeGIS in a Tablet PC.

Some Remarks and Further Developments

BeeGIS is a very promising tool for geologists or any field operator. GPS, Geonotes, Fieldbook image editor, and annotations tools are the most noteworthy and distinctive features of this software. They can help make a geologist very comfortable during field work, as one may now be with pencil and paper.

In the latest versions of BeeGIS, the management of raster images (that is, aerial photographs), maps (that is, topographic maps), and vector data has been significantly improved, as well as the performance and functionality of the embedded database. Also, the ability to synch with other devices has been implemented in order to exploit the use of tools such as cameras, GPS, and the compass available in the new generation of smart phones.

Some field work project needs a prearranged form to store standard data. At the moment, the development roadmap schedules the creation of new tools that allow any people/organizations/companies with limited knowledge of digital work to create and to manage their own survey forms.

To download the latest version of the software and to join the community of users and developers, please see *http://www.beegis.org*.

Acknowledgments

HP Technology for Teaching Higher Education Grant (2008) is helping the development of BeeGIS by awarding the project: “Territorial data capture and analysis for Applied Computer Science, Earth and Environmental Sciences” (responsible Prof. M. De Donatis). ARPA Piemonte financially supported part of the software designing and programming and is giving very helpful feedback from field workers. HydroloGIS is a fundamental partner in the software development and support. Authors are grateful to Dave Soller for suggestions and corrections that improved this paper.

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Converting Geologic Maps from Paper to Vector Format

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Abstract

Recent mapping projects in east-central Alabama and west Georgia have produced geologic maps at 1:24,000 scale that are useful for delineating and developing hard rock aggregate sources in the vicinity of the Fall Line, to serve one of the world's largest aggregate markets. By converting existing geologic maps from paper format to GIS vector format, geologic information can be readily accessed, and GIS analytical techniques can be utilized by mining companies to examine potential aggregate materials sources. Supplementary geological and aggregate material data can be gathered and added to the digitized versions of the geologic maps to augment the functionality of the end product.

Additionally, the project aims to develop a practical manual for the production of digital geologic maps that are compatible with formats used by the Geological Survey of Alabama and the U.S. Geological Survey. Thus far, the procedure requires that existing PDF files of geologic maps be digitized in a heads-up manner, to create feature classes contained within a personal geodatabase.

Introduction

New Federal and State regulations have increased restrictions regarding quality standards for aggregate materials used in asphalt, concrete, and other types of construction. These recent increases in restrictions have rendered many previously used 'soft' sedimentary sources of the Gulf and Atlantic Coastal Plain provinces inadequate for the production of quality aggregate stone that meets specifications. Given the high cost of transporting rock materials, the closest 'hard' rock (crystalline) aggregate materials suitable for construction projects within the Gulf and Atlantic Coastal Plains will require the development of more quarries along the Fall Line.

Geologic maps are fundamental to the mining industry because they provide the most basic information needed for exploration, development, and the reclamation of industrial stone quarries. Recent mapping projects provide the aggregate industry with valuable information on the geology in the vicinity of the Fall Line. However, these maps have not yet been produced in a vector format that would enable GIS analytical techniques and, therefore, they are less effective and the quantity of information shown on the maps is limited when compared to what could be included in a GIS file. This project uses existing maps to produce high-quality vector format maps at a scale most applicable to the exploration and development of aggregate resource sites, and aims to supplement the final product with spatial geologic data relevant to the production of high-quality aggregate stone.

Project Goals

The goal of our project is to prepare a GIS project composed of vector format, seamless geologic map information at a scale of 1:24,000 that includes five adjacent quadrangles (Tallassee, Carrville, Notasulga, Loachapoka, and Auburn quadrangles; see figure 1). The maps will contain a traditional representation of geological data, a DEM, and other available spatial information and appropriate metadata, as well as information on rock materials testing as available from governmental (for example, Alabama Department of Transportation) and industrial sources. GIS based exploration techniques pertaining to the development of aggregate material will be investigated. The maps must be seamless in order for bedrock types and their structures (for example, Appalachian folds and faults) as mapped on the individual geologic quadrangle maps

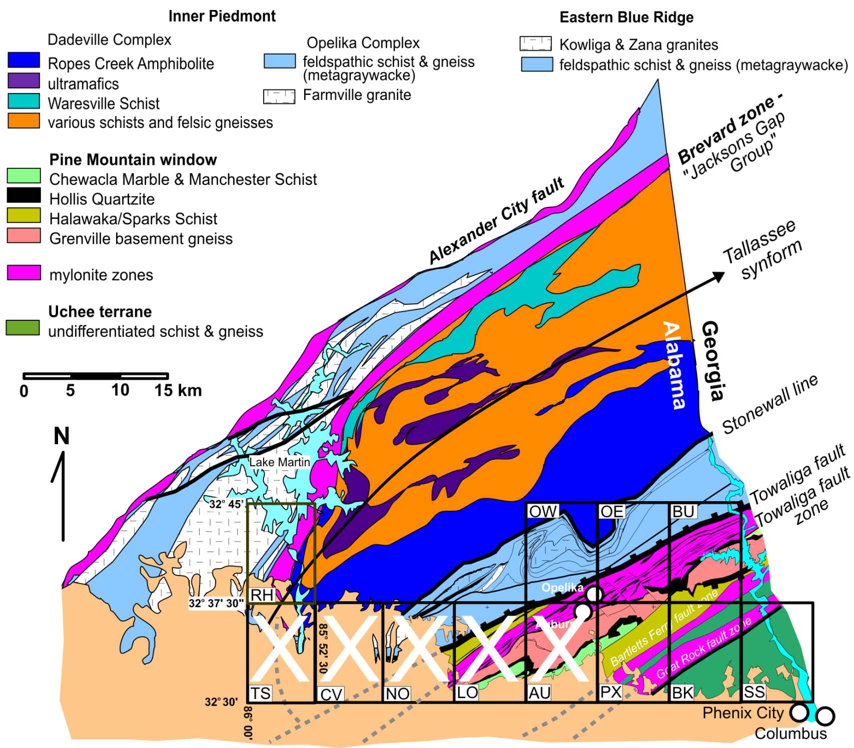

Figure 1. Fall Line quadrangles mapped, or being mapped (for example, Red Hill) by the Principal Investigator and his students, superimposed on a tectonostratigraphic map of the Alabama Piedmont (from Osborne and others, 1988; Steltenpohl, 1996; Steltenpohl and Kassos, 2003; Steltenpohl and Sterling, 2004; Steltenpohl and others, 2005; and Steltenpohl and White, 2007). The Brevard zone separates the eastern Blue Ridge from the Inner Piedmont along the west limb of the Tallassee synform. Large white X's are quadrangles we now have digitized. Coastal Plain rocks are tan colored, and dashed gray lines are sub-Coastal Plain, Piedmont geophysical lineaments from Horton and others (1984). Quad abbreviations: AU = Auburn; BK = Bleeker; BU = Beulah; CV = Carrville; LO = Loachapoka; NO = Notasulga; OE = Opelika East; OW = Opelika West; PX = Parker's Crossroads; RH = Red Hill; SS = Smith's Station; TS = Tallassee.

to follow ore seams across a broader area, in order to allow for the formulation of an exploration model. Furthermore, a manual illustrating the standard processes for the digitization of geologic maps using ArcGIS will be produced.

Methods

Data Collection

Collection of geologic data through fieldwork has been completed using conventional mapping techniques. The data have been displayed in the traditional format of 7.5-minute quadrangle geologic maps. These maps were produced using Corel Draw® and other computer graphics programs and stored as both PDF files and paper copies. Field notes taken during the mapping process are incorporated to supplement information projected on the map. Additional information will be collected using a GPS-enabled field instrument. We have found that additional fieldwork is generally needed along the borders of the individual quadrangle maps in order to assure that the rocks and structures are properly joined across their boundaries.

Digitization

The digitization process is completed using ArcGIS. A PDF file of a geologic quadrangle is loaded in ArcMap and georeferenced to its corresponding topographic quadrangle, which was acquired from Alabama View (*www.alabamaview.org*). ArcCatalog is used to create a Personal Geodatabase containing a Feature Class within a Feature Dataset. The feature type is set to Polygon Feature. A preliminary attributes table is constructed for geologic units. The new Feature Class is then added to ArcMap and the editing process begins.

A Wacom tablet and pen are used in conjunction with the editor Sketch tool to add vertices to create polygons, lines, and point data. Polygon attribute tables are populated with the appropriate data. Line features are created in a similar fashion, to represent faults and contacts. Point features and attributes are added for locations of recorded point data and include the strike and dip of units and the orientation of other features.

The methods described here are modeled after those of Philip Dinterman, Alabama Geological Survey (AGS), with some modifications. Please refer to his poster from the 2008 DMT proceedings for details on the AGS map production techniques (*http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_Dinterman.pdf*).

Progress

To date, the bedrock units on five geologic quadrangle maps (Tallassee, Carrville, Notasulga, Loachapoka, and Auburn quadrangle; see figure 1) are completely digitized. The process of revising the attribute tables is underway. Line and point data have been added to these four maps. Another quadrangle, the Auburn quadrangle, is in preparation for the digitization stage of the process. A manual for the process is under development and copies are available by request.

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Creation of Digital Geologic Data for Pecos National Historical Park

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Geologic Resources Inventory

The Geologic Resources Inventory (GRI) is one of 12 natural resource inventory efforts within the National Park Service (NPS) Inventory and Monitoring Program. The GRI aims to raise awareness about geology and the role geologic features and processes play in the environment. The Inventory and Monitoring Program serves natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel.

The GRI team, working closely with the Colorado State University Earth Science Department and a variety of other partners, provides each of the 270 natural area parks with a geologic scoping meeting, digital geologic map data, and park specific geologic report. These products are designed to enhance stewardship of park resources by providing valuable information about geologic formations, hazards, and links between geology and other natural resources.

The digital geologic maps prepared for the GRI reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps may be used by the GRI as sources of information to create digital data in order to meet a park's specific needs and assist with resource management issues. As of May 2009, the GRI program has scoped 234 parks, completed digital datasets for 143, and has written reports for 50. All the GRI products are available on the GRI products Web site (*http://www.nature.nps.gov/geology/inventory/gre_publications.cfm*). Digital geologic maps are posted on the Natural Resource Information Portal (*http://nrinfo.nps.gov/*).

This paper describes our methods for processing the geologic map information for a park, and producing the various products needed. Methodologies are summarized in the poster (fig. 1).

Acquiring Geologic Data for Pecos National Historical Park

The GRI Scoping meeting for Pecos National Historical Park (NHP) was held in March 2006 and included attendees from the NPS and the New Mexico Bureau of Geology and Mineral Resources (NMBGMR). The participants evaluated the extent and quality of existing geologic maps and discussed park-specific geologic resource management issues. Participants agreed that the NMBGMR's Preliminary Geologic Map of the Glorieta 7.5-minute Quadrangle (Ilg and others, 1997) and the Preliminary Geologic Map of the Pecos 7.5-minute Quadrangle (Read and Rawling, 2002) provided the most recent geologic mapping at the largest scale available for the area. Accordingly, these two quadrangles were utilized to create the GRI Geology Geodatabase for Pecos NHP. The NMBGMR agreed to supply the GRI with the digital shapefiles for the Pecos quadrangle. Since no GIS data were available for the Glorieta quadrangle, the GRI decided to digitize it, using the Adobe Acrobat version of the map. Additionally, the GRI agreed to provide the NMBGMR with a copy of the Digital Geologic Map of Pecos National Historical Park and Vicinity, New Mexico, upon its completion.

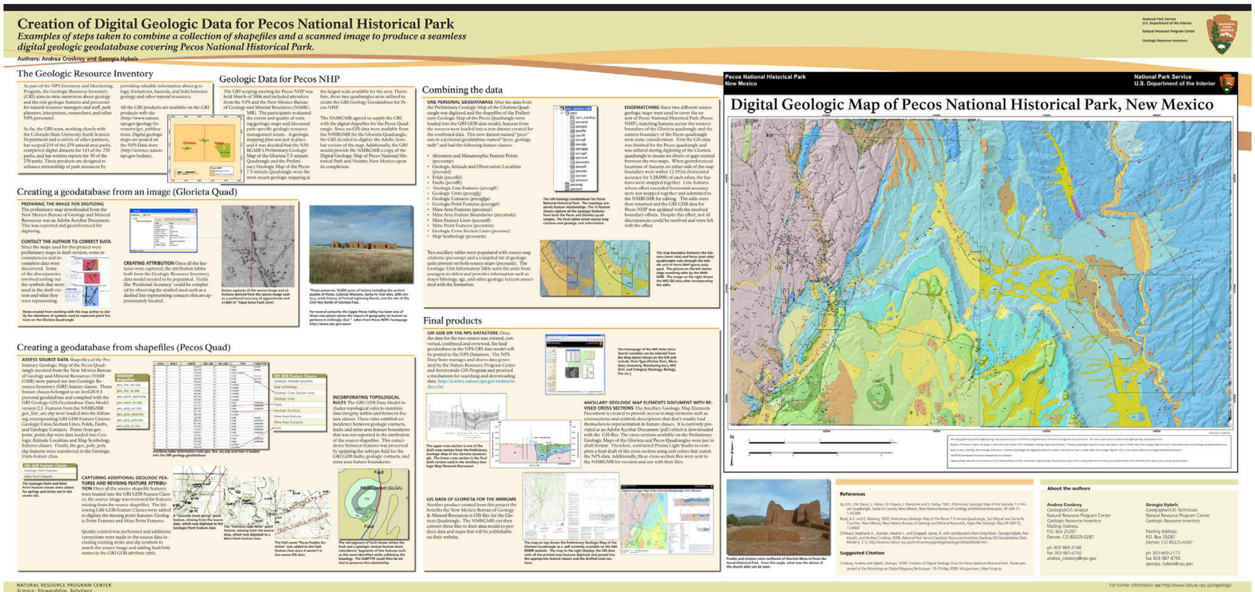

Figure 1. Creation of digital geologic data for Pecos National Historical Park (a full-resolution copy of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Croskrey.pdf*).

Digitizing Geologic Data for the Glorieta 7.5′ Quadrangle

The preliminary map downloaded from the New Mexico Bureau of Geology and Mineral Resources was an Adobe Acrobat document (Ilg and others, 1997). This map was exported and georeferenced for digitizing in ESRI ArcMap. The maps used for this project were preliminary maps in draft version; consequently, some inconsistencies and incomplete data were discovered. Some of the discrepancies involved incomplete map boundaries, inconclusive map labels, and difficult-to-read symbology that lacked a symbol key with definitions.

Once all the features were captured, the attribution tables built from the GRI Geology-GIS Geodatabase Data Model version 2.1 (O'Meara and others, 2008) were populated with information from the map. Fields, such as 'Positional Accuracy', were attributed by interpreting the symbols used on the source image and the description of that symbol in the legend, such as a dashed line representing contacts that are approximately located. Other line types represented on the source image and attributed in the table included known or certain, concealed, inferred, approximate and queried, quadrangle boundary, and water or shoreline.

Converting Digital Geologic Data for the Pecos 7.5′ Quadrangle

Assessing Source Data

Shapefiles of the Preliminary Geologic Map of the Pecos quadrangle received from the NMBGMR were parsed out into GRI feature classes. These feature classes were in an ArcGIS 9.3 personal geodatabase, and complied with the GRI Geology-GIS Geodatabase Data Model version 2.1 (O'Meara and others, 2008). Geologic line features from the NMBGMR geo_line_arc.shp were loaded into the following corresponding GRI Geodatabase Feature Classes: Geologic Cross Section Lines, Folds, Faults, and Geologic Contacts. Point data from geo_point_point.shp were loaded into Geologic Attitude Localities and Map Symbology features classes. Finally, the geo_poly_poly.shp features were transferred to the Geologic Units feature class.

Capturing Additional Geologic Features and Revising Feature Attribution

Once all the source shapefile features were loaded into the GRI Geodatabase feature classes, the source image (Read and Rawling, 2002) was reviewed in order to identify any features present on the source image but missing from the source shapefiles. Geologic Point Features (gpf) and Mine Point Features (min) then were added to the geodatabase, and missing point features were digitized into these feature classes. Quality control was performed and additions/corrections were made to the source data, including the rotation of strike and dip symbols to match the source image and addition of fault and fold names to the GRI Geodatabase attribute table.

Incorporating Topological Rules

The GRI Geodatabase Data Model includes topological rules designed to maintain data integrity within and between feature classes (O'Meara and others, 2008). These rules establish coincidence between geologic contacts, faults, and mine area feature boundaries that were not reported in the attribution tables of the source shapefiles. This coincidence between features was preserved by updating the subtype field for the GRI GDB faults, geologic contacts, and mine area feature boundaries.

Combining the Data from the Quadrangles

One Personal Geodatabase

After the data from the Preliminary Geologic Map of the Glorieta Quadrangle were digitized and the shapefiles of the Preliminary Geologic Map of the Pecos Quadrangle were loaded into the GRI GDB data model, features from the sources were loaded into a new dataset created for the combined data. This new personal geodatabase named "peco_geology.mdb" contains the following feature classes: Alteration and Metamorphic Feature Points (pecoamp), Geologic Attitude and Observation Localities (pecoatd), Folds (pecofld), Faults (pecoflt), Geologic Line Features (pecoglf), Geologic Units (pecoglg), Geologic Contacts (pecoglga), Geologic Point Features (pecogpf), Mine Area Features (pecomaf), Mine Area Feature Boundaries (pecomafa), Mine Feature Lines (pecomfl), Mine Point Features (pecomin), Geologic Cross Section Lines (pecosec), and Map Symbology (pecosym).

Two ancillary tables were populated with source map citations (pecomap) and a compiled list of geologic units present on both source maps (pecounit). The Geologic Unit Information Table (pecounit) sorts the units from youngest to oldest and provides information associated with each formation such as major lithology, age ranges, and geologic keywords.

Edge-Matching

Since two different source geologic maps were used for Pecos NHP, the matching of features across the western boundary of the Glorieta quadrangle and the eastern boundary of the Pecos quadrangle required some consideration. First, the GIS data were finalized for the Pecos quadrangle, and then were utilized while digitizing the Glorieta quadrangle in order to ensure that no slivers or gaps were created between the two maps during the digitizing process. When georeferenced locations of features on either side of the map boundary were within 12.192 m (U.S. National Map Accuracy Standards for 1:24,000 scale) of each other, the features were snapped together. Line features whose offset exceeded this horizontal accuracy were not snapped together; they were instead submitted to the NMBGMR for editing. When the edits were returned to us, the peco_geology.mdb for Pecos NHP was updated with the resolved boundary offsets. Despite this effort, not all discrepancies could be resolved, and some offsets remain. This was the case for some Quaternary deposits that were subdivided on the Pecos quadrangle but lumped on the Glorieta quadrangle.

Final Products

GRI GDB in the NPS Data Store

When the combined data from the two sources has been reviewed, the final geodatabase will be posted to the NPS Data Store. The NPS Data Store manages and shares data generated by the Natural Resource Program Center and Servicewide GIS Program, and provides a publicly accessible mechanism for searching and downloading data (*http://science.nature.nps.gov/nrdata/index.cfm*).

Ancillary Geologic Map Elements Document with Revised Cross Sections

The Ancillary Geologic Map Elements Document provides access to map elements such as cross sections and symbol descriptions that do not readily lend themselves to representation in feature classes. It is currently provided as an Adobe Acrobat document (pdf) downloadable with the GIS files. The cross sections, available on the Preliminary Geologic Maps of the Glorieta and Pecos Quadrangles, were in draft format (Ilg and others, 1997; Read and Rawling, 2002). The GRI contracted with Prisma Light Studio to complete a final draft of the cross section using geologic unit colors that match the NPS data. Additionally, these cross section files were sent to the NMBGMR for revision and use in their projects.

GIS Data of Glorieta for the NMBGMR

Another product created from this project that benefits the New Mexico Bureau of Geology and Mineral Resources is the GIS files for the Glorieta quadrangle. The NMBGMR can convert these files to their data model to produce data and maps that will be publishable on their Web site.

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Shepherding Geologic Data from the Outcrop to Publication (and Beyond?)

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Abstract

In 2008 it was recognized that the Alaska Division of Geological & Geophysical Surveys (DGGS) was not meeting some self-prescribed performance targets for publication of geologic data. Consequently, the State Geologist established a committee to review the process by which DGGS collects and publishes geologic data and to make recommendations to the State Geologist for means to streamline the process. An analysis of time spent completing common tasks shows that DGGS staff who are involved in developing publications are overcommitted with other projects that are key to the mission of the agency. These obligations generally cannot be set aside to complete publications; therefore, time needed to facilitate publication must come from streamlining the outcrop-to-publications process and possibly from additional staffing (presented at the DMT'09 meeting as a poster; see *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Athey.pdf*).

Five-Year Publication Rate

Over the past 5 years DGGS has published only one-third of the total maps intended for publication (table 1). Geologic maps that were published during that time period generally took 2 years to process from fieldwork to public release. Maps that have not been completed have been in the queue for up to 10 years. DGGS tends to release preliminary geologic information at technical meetings, as PowerPoint presentations and posters, to get the data out to the public as quickly as possible. However, the data still require publication in one of DGGS's peer-reviewed report or map series before they are formally released to the public. Ideally, DGGS would like to publish all geologic maps in 1.5 to 2 years following completion of field projects.

DGGS does not have a similar delay publishing raw geologic data files or interpretive text reports. Data releases do not require a technical review and are typically published soon

Table 1. Portion of DGGS geologic maps initiated in 2003–2007 that have been published.
Note: Geologic maps initiated by the Volcanology section generally require more time to publish because event response duties take precedence over all other functions of that section.

Geologic Section within DGGS	Maps Initiated	Maps Published	Success Rate
Energy Resources	3	1	33%
Mineral Resources	6	3	50%
Engineering Geology	15	6	40%
Volcanology	5	0	0%

after the analyses are completed. Text reports that contain data and interpretation are usually published within 3 years of the fieldwork. Geologic maps, however, tend to take 2–10+ years.

Current and Historic Workflow

Prior to 1994, DGGS's turnaround time on one geologic map from field data collection to final printed product averaged 6–7 years. The manual cartography alone took six months to a year to complete. DGGS implemented GIS (Unix-based ArcInfo 4.2) in lieu of manual cartography in 1989 and published the first GIS-based map in 1994. At approximately the same time, DGGS started accepting funding from the federal STATEMAP program, for which DGGS was required to produce a near-publication-quality map in 1 year. The new GIS system and the STATEMAP 1-year deadline provided DGGS with the momentum to decrease geologic map processing time to 2–3 years, and eventually to 2 years. In all cases where the geologic mapping was funded by the STATEMAP program, the 1-year draft map deliverable was completed. Staffing and communication issues kept some geologic maps from progressing to completion.

In the days of manual cartography, DGGS had 2–3 cartographers and one editor on staff. The cartographers only drafted the highest level of reports—Professional Report series—and geologists completed pen and ink cartography on all other maps. An editor and only one cartographer remained shortly after DGGS transitioned to GIS-based cartography (Davidson, 1998). The cartographer became a GIS data manager and eventually the ESRI-product license manager, and currently does not draft geologic maps. Interns and journey-level geologists learned GIS and took over the cartographic duties. Now more than half of the geologists at DGGS usher their own geologic maps through the entire publication process, including fieldwork (arranging extensive logistics, contracting, budgeting, data collection), spatial analysis and digital drafting (using ArcGIS 9.3 [*http://www.esri.com/*] and MapInfo Professional 9.5 [*http://www.pbinsight.com/*]), metadata writing, and archiving. Almost all routine spatial analysis and cartographic tasks completed at the survey are performed by mid- or senior-level geologists, although many DGGS geologists are GIS-capable, with moderate to extensive experience using GIS software (fig. 1).

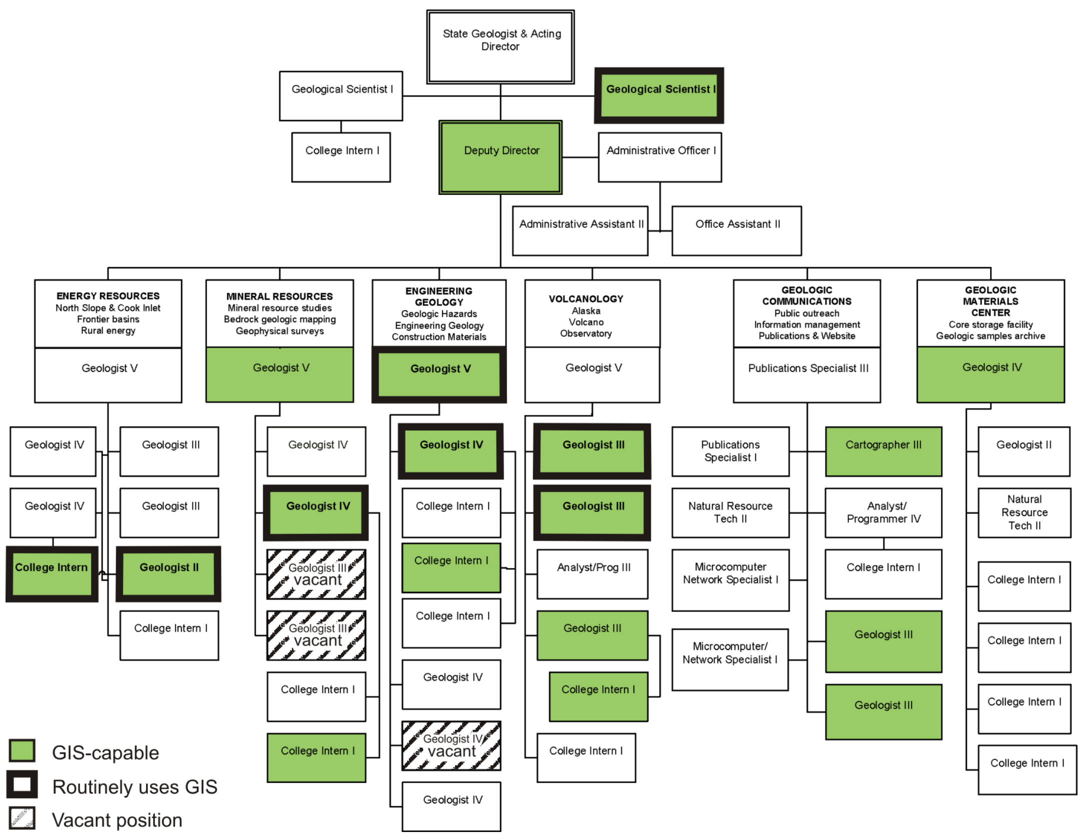

Figure 1. DGGS's organizational chart (August 2009). The survey contains five sections, each with a different focus: Engineering Geology, Energy Resources, Mineral Resources, Volcanology, and Geologic Communications. The Geologic Materials Center is a separate facility located in Eagle River, Alaska. Geologist positions are ranked 1 through 5. Geologist V's are typically section supervisors.

Review Process

DGGS established a committee to find out why geologic maps are stalling in the publication process and to recommend improvements to the process. The review committee was formed in November 2008 and met several times per month until May 21, 2009. The committee was composed of several members of each of the five DGGS sections. Committee members agreed on specific questions to answer, compiled the data, and then discussed each topic. Below are the major questions discussed by the committee.

Question: On what tasks are employees spending their time? Can some tasks be sacrificed in order to spend more time on publishing geologic maps?

Finding: The committee created a list of 11 common, broadly defined tasks, and asked each employee except upper management, administrative support, and interns to classify how much time they spend on each task. The data show that less than 10 percent of time resources can be redistributed in most sections to spend more time on map-based and non-map-based geologic data. Most tasks performed by each section are mandatory to the DGGS's mission and cannot be deferred or suspended (fig. 2).

Question: How can the outcrop-to-publication process be made more efficient?

Finding: Each section created a flow chart that identified problem areas and bottlenecks. When similar problems were found in at least two sections, solutions were discussed. Problems are wide ranging; however, most solutions fall into two categories—various means to free up geologists' time to work on key tasks, and the implementation of new technology. Some specific ideas discussed to streamline the process include revamping the procurement process, initiating digital geologic field mapping (Athey and others, 2008), and buying or creating software applications to automate tasks where possible (Papp, 2005; Papp and others, 2007). Training staff on applications and the use of new technologies ultimately would save time overall.

Question: Are publication-related tasks being completed by the most appropriate staff members?

Finding: Staff created an inclusive list of tasks necessary to prepare and publish geologic data, and each section recorded both the staff member(s) currently responsible for the task and the staff member(s) who would be most appropriate for the task. The spreadsheets clearly show that DGGS suffers from a lack of support staff (fig. 3). Each section noted that some tasks being performed by mid- to senior-level geologists would more appropriately be performed by interns, journey-level geologists (for example, geologist levels 1 and 2), GIS technicians (a job class not currently employed by DGGS), and non-specialized natural resource technicians. Increasing DGGS's support staffing is the highest priority to improve the effectiveness of our outcrop-to-publications mapping process.

As part of the review process, the committee contacted five other State geological surveys directly and canvassed several others at the DMT'09 conference. Our brief survey indicated that other State geological surveys have significant cartographic/GIS support staff as part of their map publication process. The ratio is approximately 1 GIS technician to 5 geologists. Even though some of these organizations are still

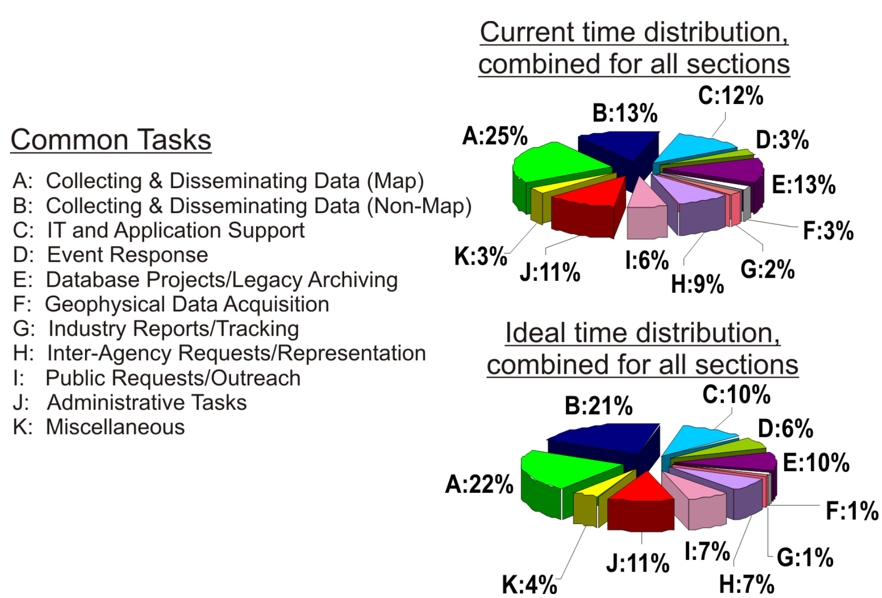

Figure 2. Current and ideal employee time distribution on common tasks. Ideally, DGGS would like to produce an equal number of geologic maps and non-map geologic publications.

TASK	NRT	INTERN	GEO I	GEO II	GEO III	GEO IV	GEO V
Field work tasks							
Assemble and deploy field gear		M			M	M	m
Supervise field personnel					M	M	
Maintain field office and communications equipment		M			M	m	m
Collect field data and samples					M	M	M
Preliminary interpretation and mapping					M	M	M
Organize samples for transport/shipping		M			m	m	m
Enter field data into database		M			m	m	
Complete draft field map					M	M	m
Disassemble and demob field gear		M			M	M	M
Return field gear to warehouse		M			M	M	M

Figure 3. Excerpt from task-staffing spreadsheet filled out by the Mineral Resources section. Because of the high turnover rate of student interns, constant training is a necessity. Mineral Resources section would prefer a permanent Geologist I series staff member to complete recurring tasks. Column headings indicate job class: NRT = Natural Resource Technician; Intern = undergraduate or graduate level student intern; Geo I–V = Geologist series. Cells marked with a 'M' or 'm' indicate the current (August 2009) scenario of task completion in the Mineral Resources section. 'M' indicates that an employee of the specified job class currently performs a major role in the completion of the task; 'm' indicates that an employee of the specified job class currently performs a minor role in the completion of the task. Shaded cells indicate the hypothetical, best-case scenario of task completion in the Mineral Resources section. Dark shaded boxes indicate the most appropriate job class to perform a major role in the completion of the task; light shaded boxes indicate the most appropriate job class to perform a minor role in the completion of the task.

having difficulties meeting their mapping obligations, the extent of their shortfalls appear to be less significant than DGGS's.

The committee recommended hiring four new positions to be shared among the geologic projects—two logistics/equipment technicians (Natural Resource Technicians) and two GIS technicians—to significantly improve timely output of map and non-map publications. Logistics/equipment technicians would primarily organize and maintain field equipment and arrange field logistics, tasks that take several months for each project. GIS technicians would complete the digital cartography of a geologic map after the geologist finalizes the map's vector and attribute data. In the future, when the publication of geologic maps in GIS database form becomes routine, database preparation and publication will likely be completed through a collaborative effort by the geologist and the GIS technician. Whether in paper or digital form, project geologists would remain ultimately responsible for the map's production. The new shared positions are expected to allow more time for geologists to focus on the geologic science necessary to complete their publications, resulting in the most effective changes to the outcrop-to-publication process.

Conclusion

In general, the review committee believes that DGGS is collecting the correct amount of geologic data and covering an acceptable amount of area. However, geologic map publication is lagging behind data collection because DGGS geologists are overcommitted. Currently, if a geologist must set his/her project aside to work on something else, there are no other geologists available to step in and move the project forward. Because there are always new projects cycling through, older unfinished projects rarely get completed. DGGS's solution is to hire appropriate new support staff and increase efficiency within the outcrop-to-publication process to create flexibility in project schedules and help expedite publication output. It is critical that staffing levels be reasonably balanced with existing and future workloads.

Discussion

During the review process, DGGS identified, but did not resolve, several questions related to data collection and distribution. As these issues are probably commonplace among State geological surveys and will only become more relevant, discussion and planning now will help with future decisions and ease whatever transitions are needed.

Should DGGS Eventually become a Paperless Organization?

DGGS strives to make our geologic data widely available online. All DGGS and U.S. Geological Survey (USGS) Alaskan publications are available for free download on our Web site as PDF or Lizardtech MrSID format (*http://www.dggs.dnr.state.ak.us/index.php?menu_link=publications&link=publications_search*). In addition, DGGS developed an enterprise Oracle database that houses and will serve analytical and spatial data (Freeman, 2001a, b; Freeman and others, 2002; Freeman and Sturmann, 2004). DGGS is currently developing a Web Feature Service (WFS) via GeoServer (*http://geoserver.org/*) to make these data available to the public. Some DGGS digital and analytical data are already available for download on our Web site (*http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=digitaldata*; *http://www.dggs.dnr.state.ak.us/webgeochem/*).

Since all of this information is available online, does the public need paper maps to be available as well? At the moment, the answer is yes. Many users do not have high-speed internet capable of downloading large files, or easy access to plotters. Also, most users lack the software and GIS skills necessary to create maps from digital data. DGGS will undoubtedly revisit this question as user expectations change with technological advances.

Should DGGS have a Software Development Group?

Regular maintenance of the enterprise Oracle database, creation of Web-database interfaces, Web site maintenance, and delivery of online interactive spatial data require time-consuming and expensive programming time. In addition, each new in-house application that goes online requires maintenance, which leaves less time for project development. DGGS currently employs only one analyst/programmer dedicated to these tasks. To date, most of the Web-database and online interactive spatial data interface development has been contracted out. However, this strategy has met with limited success as the deliverables often do not meet specifications. Another option is to train other staff members to assist; however, minimal staff time is available, the training itself is time consuming, and programming by a novice takes much longer to complete. Ideally, additional analyst/programmers would be hired to round out the group, but new staff positions are difficult to secure in the State's current fiscal climate.

How Much Time Should DGGS Allot to Compiling and Inputting Legacy and Other Agencies' Data?

DGGS functions as the State's lead source and repository of Alaska geologic information and the primary source of information concerning Alaska's energy resources, mineral resources, and geologic hazards. Currently, DGGS is concentrating on archiving its own historical and current project data. Various other agencies, institutions, and students have also produced data for Alaska that eventually should be compiled in DGGS's enterprise Oracle database. In recent years, DGGS has accepted funding to compile and make accessible certain "at risk" datasets such as geochronologic and geochemical analytical data (*http://www.dggs.dnr.state.ak.us/webgeochem/*). DGGS will continue to prioritize which datasets should be compiled, archived, and disseminated to the public and to work on them as time allows.

How will DGGS Keep Data Current in the Enterprise Oracle Database?

The integration of data loading and database maintenance into DGGS's business process will help ensure that DGGS's data are kept up to date. The creation of user-friendly data loading forms, clear documentation, and staff training will also facilitate data loading. How other agency, institutional, and student data will be kept current is less clear. To maintain the most reliable and up-to-date non-DGGS records, a staff member will probably need to be dedicated to harvest data on specific topics and enter the data into DGGS's database. This is currently how we ensure that all Alaska USGS publications are included in our online publications database, but it is a time-consuming process. Another method would be to lobby laboratories and authors to voluntarily send us their data or to enter it into the database themselves via a Web interface. This latter scenario would require persuading an entity that the effort would be worthwhile.

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