Digital Mapping Techniques '08

Association of American State Geologists

United States Geological Survey

Digital Mapping Techniques '08—Workshop Proceedings

May 18–21, 2008
Moscow, Idaho

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

U.S. Geological Survey Open-File Report 2009–1298

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

Digital Mapping Techniques '08—Workshop Proceedings

Edited by David R. Soller

May 18–21, 2008
Moscow, Idaho

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

Hosted by the
Idaho Geological Survey

U.S. Geological Survey Open-File Report 2009–1298
2009

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

CONTENTS

Poster Presentations

Introduction

By David R. Soller

U.S. Geological Survey
926-A National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6977
email: *drsoller@usgs.gov*

The Digital Mapping Techniques '08 (DMT'08) workshop was attended by more than 100 technical experts from 40 agencies, universities, and private companies, including representatives from 24 State geological surveys (see Appendix A). This workshop, hosted by the Idaho Geological Survey, from May 18-21, 2008, on the University of Idaho campus in Moscow, Idaho, was similar in nature to the previous 11 meetings (see Appendix B). 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.

Each DMT workshop has been coordinated by the Association of American State Geologists (AASG) and U.S. Geological Survey (USGS) Data Capture Working Group, the latter of which was formed in August 1996 to support the AASG and the USGS in their effort to build a National Geologic Map Database (see Soller and Stamm, this volume, and *http://ngmdb.usgs.gov/info/standards/datacapt/*). The Working Group was formed because increased production efficiencies, standardization, and quality of digital map products were needed for the database—and for the State and Federal geological surveys—to provide more high-quality digital maps to the public.

At the 2008 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 Idaho Geological Survey (IGS) and the Director and State Geologist, Roy Breckenridge, for hosting this meeting. Loudon Stanford and Jane Freed coordinated the event; their management was flawless. It has been my distinct pleasure to work with them on various DMT-related activities over the years. I also thank Jennifer Rice and Linda Newberry for providing the registration and conference services that ensured the meeting's success.

I also thank the members of the Data Capture Working Group (Warren Anderson, Kentucky Geological Survey; Sheena Beaverson, Illinois State Geological Survey; Elizabeth Campbell, Virginia Division of Mines and Geology; Scott McColloch, West Virginia Geological and Economic Survey; George Saucedo, California Geological Survey; Loudon Stanford, Idaho Geological Survey; and Tom Whitfield, Pennsylvania Geological Survey), for advice in planning the workshop's content. Scott McColloch graciously served as peer reviewer of the Proceedings.

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 16 oral presentations, 3 discussion sessions, and 19 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 12 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/DMT08presentations.html*.

The Next DMT Workshop

The 13th annual DMT meeting will be held in the Spring of 2009 on the campus of West Virginia University in Morgantown, West Virginia. 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]

Alaska Division of Geological and Geophysical Surveys
Jennifer Athey
Seth Snedigar

Arizona Geological Survey
Ryan Clark

Arizona Geological Survey / USGS
Steve Richard

California Geological Survey
Carlos Gutierrez
George Saucedo

Central Washington University
Robert Hickey

Colorado State University / National Park Service
Stephanie O'Meara
Ronald Karpilo

ESRI, Inc.
Charlie Frye
Peter Kasianchuk
Willy Lynch
Steve Mulberry

Geological Survey of Alabama
Philip Dinterman

Geological Survey of Canada
Peter Davenport
Parm Dhesi
Vic Dohar
Linda Guay
Jamel Joseph
Roger Macleod
Marianne Quat
Carol Wagner

Geological Survey of Finland
Hannu Idman
Jyrki Kokkonen
Jouni Vuollo

Hecla Mining Company
Deb Glader
Jim Myers
Brandi Rollins

Idaho Geological Survey
Roy Breckenridge
Jane Freed
Dean Garwood
Reed Lewis
William Phillips
Loudon Stanford
Benjamin Studer

Illinois State Geological Survey
Sheena Beaverson
Jane Domier

Kentucky Geological Survey
Gerald Weisenfluh

Louisiana Geological Survey
Robert Paulsell

Minnesota Geological Survey
Harvey Thorleifson

Missouri Division of Geology and Land Survey
Edie Starbuck

Montana Bureau of Mines and Geology
Ken Sandau
Susan Smith

National Park Service
Gregory Mack
Georgia Hybels

Nevada Bureau of Mines and Geology
Christine Arritt
Jordan Hastings
Peter House
Jennifer Mauldin

New Mexico Bureau of Geology and Mineral Resources
Glen Jones

Ohio Division of Geological Survey
James McDonald
Kelli Vogt

Oregon Department of Geology & Mineral Industries
Jed Roberts
Ian Madin

Pennsylvania Geological Survey
Rose-Anna Behr
Thomas Whitfield

Portland State University
David Percy

SNS Silver Corp.
Jesse Bird

South Carolina Geological Survey
Scott Howard

U.S. Geological Survey
Mary Digiacomo-Cohen
Christopher Garrity
Ralph Haugerud
Chad Hults
Keith Labay
Nancy Norvell
Randall Orndorff
Sue Priest
Lydia Quintana
David Soller
Nancy Stamm
Will Stettner
Byron Stone
Scott Van Hoff
Ronald Wahl
Frederic Wilson

University of Alabama
Douglas Behm

University of Idaho
Melissa Sabga
Travis Steel
Theresa Taylor

University of Nebraska, Conservation and Survey Division
Les Howard

University of Tennessee
Andrew Wunderlich

USDA Forest Service
Andrew Rorick

Utah Geological Survey
Kent Brown
Jared Ehler

Washington Geology and Earth Resources Division
John Bromley
Recep Cakir
Charles Caruthers
Trevor Contreras
Kelsay Davis
Bryan Garcia
Isabelle Sarikhan

West Virginia Geological and Economic Survey
Gayle McColloch
Jane McColloch

William Lettis and Associates
Mark Zellman

Wisconsin Geological and Natural History Survey
Bill Bristoll
Deborah Patterson
Kathy Roushar
Peter Schoephoester

Wyoming Geological Survey
Allory Deiss
Richard Jones
Phyllis Ranz

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/*.

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

Oral Presentations

Braving the Rocky Waters – Standards Development and the U.S. National Geologic Map Database
By David R. Soller and Nancy R. Stamm (U.S. Geological Survey)

Digital Geologic Mapping at CGS – Basic Data for Analysis of Geologic Resources and Hazards
By George J. Saucedo, Chris J. Wills, and Carlos I. Gutierrez (California Geological Survey)

The Transition from Traditional to Digital Mapping: Maintaining Data Quality while Increasing Geologic Mapping Efficiency in Alaska
By Jennifer E. Athey, Lawrence K. Freeman, and Kenneth A. Woods (Alaska Division of Geological and Geophysical Surveys)

The State of the State Data: An End-User’s Perspective
By Mark Zellman, David Slayter, Ranon Dulburg, Marco Ticci, Kevin Whaley, Jeff Hemphill, and Jason Finley (William Lettis & Associates, Inc.)

Rescuing Legacy Digital Data: Maps Stored in Adobe Illustrator™ Format
By Andrew L. Wunderlich and Robert D. Hatcher Jr. (Tectonics and Structural Geology Research Group, University of Tennessee, Knoxville)

ESRI Cartographic Representations for the FGDC Digital Cartographic Standard for Geologic Map Symbolization – A Preliminary Report
By Peter M. Kasianchuk and Charlie Frye (ESRI)

Copper Archiving and Stone Printing
By Will Stettner and Robert Kelley (U.S. Geological Survey)

Geologic Quadrangle Mapping Using High Resolution LiDAR: Promise and Problems
By Ian Madin (Oregon Department of Geology and Mineral Industries)

The National Survey and Analysis Alaska Database: Extensions To Produce the International Polar Year Circum-Polar Bedrock Geologic Map
By Frederic H. Wilson, Chad P. Hults, Keith A. Labay, and Nora Shew (U.S. Geological Survey)

Geologic Mapping and LiDAR
By Ralph Haugerud (U.S. Geological Survey)

Development of Standard Vocabularies for the U.S. National Geologic Map Database and the CGI-GeoSciML Working Group
By Steve Richard (Arizona Geological Survey / U.S. Geological Survey) and David R. Soller (U.S. Geological Survey)

Tracking New and Ongoing Geologic Mapping in the U.S. – The National Cooperative Geologic Mapping Program’s Mapping in Progress Database
By Lydia Quintana, Nancy R. Stamm, Randy Orndorff (U.S. Geological Survey)

Kentucky Field Data Entry Tools Developed in ArcIMS
By Gerald A. Weisenfluh and Douglas C. Curl (Kentucky Geological Survey)

ESRI Presentation and Demonstration on “Enterprise Management and Dissemination of Geographic Information”
By Steve Mulberry (ESRI)

National Geologic Map Databases of Afghanistan and Liberia
By Ronald R. Wahl (U.S. Geological Survey)

Defining a Three Dimensional Geologic Map for the Appalachian Plateau
By Gayle H. McColloch, Jr., and Jane S. McColloch (West Virginia Geological and Economic Survey)

Global Mapper: The Swiss Army Knife for GIS!
By Kent D. Brown and J. Buck Ehler (Utah Geological Survey)

Poster Presentations (listed alphabetically, by author):

Bringing Geological Mapping into the Digital Era - A Finnish Case
By Niina Ahtonen, Hannu Idman, Esa Kauniskangas, Jarmo Kohonen, Jyrki Kokkonen, Jouni Luukas, Jukka-Pekka Palmu, and Jouni Vuollo (Geological Survey of Finland)

Creating a Virtual Geologic Map and Field Trip of the St. George 30’ x 60’ Quadrangle, Washington County, Utah – An Adventure in Google Earth
By Kent D. Brown, Lance B. Weaver, and Robert F. Biek (Utah Geological Survey)

Digital Mapping Process of Seismic Design Category Information for Residential Construction in Washington
By Recep Cakir, Timothy J. Walsh, Karen D. Meyers, Anne C. Heinitz, Elizabeth E. Thompson, Isabelle Y. Sarikhan, Charles G. Caruthers, Jaretta M. Roloff, and David K. Norman (Washington Division of Geology and Earth Resources)

ArcMap tools for geologic map and database construction at the Arizona Geological Survey
By Ryan Clark (Arizona Geological Survey)

Digital Map Production and Publication at the Geological Survey of Alabama
By Philip A. Dinterman, G. Daniel Irvin, and W. Edward Osborne (Geological Survey of Alabama)

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

ESRI Cartographic Representations for Geologic Mapping
By Peter Kasianchuk and Charlie Frye (ESRI)

Creating Geologic Maps for the Appalachian Plateau in a GIS Environment
By Jane S. McColloch and Gayle H. McColloch, Jr. (West Virginia Geological and Economic Survey)

Project-Management GIS Applications and Tools for Coastal-Erosion Mapping in Ohio
By James McDonald (Ohio Division of Geological Survey)

Evolution of the NPS GRE Geology-GIS Data Model (1998 to 2008)
By Stephanie A. O'Meara, Heather I. Stanton, James R. Chappell, and Ronald D. Karpilo (Colorado State University)

A simplified database design, for publication of single geologic maps ("NGMDB-lite")
By Stephen M. Richard (Arizona Geological Survey / U.S. Geological Survey), David R. Soller (U.S. Geological Survey), and Jon Craigue (U.S. Geological Survey)

Sharing Technical Information with Nontechnical Users – An Example from the Monterey Bay Area Quaternary Fault Atlas
By Lewis I. Rosenberg (Tierra Geoscience)

Washington Geological Survey GIS Statewide Landslide Database – From Design to Implementation
By Isabelle Sarikhan and Kelsay M.D. Stanton (Washington Geology and Earth Resources Division)

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

Improving the Legibility of Base Maps for Geologic Mapping at the Missouri Division of Geology and Land Survey
By Edith Starbuck and Karen Loveland (Missouri Department of Natural Resources, Division of Geology and Land Survey)

A structural analysis of the Waha escarpment, utilizing LiDAR data to obtain slope and orientation of basalt bedding planes
By Travis Steel (University of Idaho)

Migrating the surficial mapping process from paper to digital format
By Kelli L. Vogt, Joseph G. Wells, Erik R. Venteris, Douglas L. Shrake, Glenn E. Larsen, Richard R. Pavey, and Michael P. Angle (Ohio Geological Survey)

Progress Toward More Detailed Site-Conditions Maps for California
By Chris J. Wills, Carlos I. Gutierrez, and Michael A. Silva (California Geological Survey)

The National Survey and Analysis Alaska database: Extensions to produce the International Polar Year Circum-Polar Bedrock Geologic Map
By Frederic H. Wilson, Chad P. Hults, Keith A. Labay, and Nora Shew (U.S. Geological Survey)

Summary of DMT'08 Discussion Sessions

By David R. Soller

U.S. Geological Survey
926-A National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6977
email: *drsoller@usgs.gov*

The DMT'08 meeting provided several opportunities for group discussion of technical issues. These sessions ranged from structured presentations by ESRI on enterprise data management and implementation of the FGDC geologic map symbol standard, followed by discussion periods, to informal discussions of cartographic techniques and methods of data preservation. Given the significance of the discussion topics, and the proportion of the meeting's time allotted to them, summaries are provided here.

1. ESRI Cartographic Representations for the FGDC Digital Cartographic Standard for Geologic Map Symbolization – A Preliminary Report

   By Peter M. Kasianchuk and Charlie Frye (ESRI; cfrye@esri.com)

In this session, ESRI provided an update on their work with the FGDC Geologic Data Subcommittee and the National Geologic Map Database (NGMDB) project to prepare an ArcGIS implementation of the FGDC geologic map symbol standard (*http://ngmdb.usgs.gov/fgdc_gds/*). This implementation, based on ESRI's Cartographic Representation rules, is intended to produce print-quality maps from a GIS. The purpose of this session was to show what was possible, and to engage the attendees during and after the session, in order to learn more about their production work and additional requirements. The presentation and accompanying poster also outlined a prototype workflow to convert ARC/INFO coverage data into an ArcGIS 9.2 geodatabase with geologic symbology stored within it.

2. ESRI Presentation and Demonstration on "Enterprise Management and Dissemination of Geographic Information"

   By Steve Mulberry (ESRI; smulberry@esri.com)

This session examined how ESRI approaches the enterprise notion of authoring, publishing, and consuming information through the use of web services. In part, this demonstration used geologic information from the Idaho Geological Survey. Discussion topics included: (a) recent enhancements to the enterprise geodatabase, including its support for PostgreSQL and the new spatial data types in SQL Server 2008; (b) publishing maps through ArcGIS server and leveraging geospatial processing through published models; and (c) the different development approaches for creating highly interactive mapping applications for use over the World Wide Web.

3. "Preservation of Geologic Data"

   By Sheena K. Beaverson (Illinois State Geological Survey)

This session provided an opportunity for open discussion of issues related to management of geologic data collections. For example, what are particular characteristics of geologic data that must be considered in any data-preservation plan? How do we address inherent technological issues? Can we develop informed advice for agency policy makers? What needs to be done to ensure data are accessible? How do we secure support for curation of geologic data collections?

4. "Cartographic Design AND Map Production"

Moderated by David R. Soller (U.S. Geological Survey)

A central purpose of the DMT meetings has been to provide a venue for sharing information and expertise, in order to improve the methods and efficiencies of digital cartography and geologic map production. This informal, 2-hour discussion session focused on these issues.

5. "Can We Develop National Standards and Guidelines for Geologic Map Databases?"

Moderated by David R. Soller (U.S. Geological Survey)

Throughout the past decade and more, geological surveys across the nation (and the globe) have collaborated on geologic map database design, science terminology, and data interchange standards. Progress has been significant, and was in part facilitated by the 12 annual DMT meetings. Should we now evaluate and perhaps refine these standards, and recommend guidelines to our geological surveys? This discussion session addressed those issues in detail. It was resolved to build upon previous work in order to converge on a limited set of standards and guidelines for consideration by USGS and AASG, and to review at the DMT'09 meeting the progress made toward that goal. The discussion session outline is provided in the Appendix.

Appendix. Outline of DMT'08 Discussion Session "Can We Develop National Standards and Guidelines for Geologic Map Databases?"

Discussion of May 20, 2008
Moderated by David R. Soller (U.S. Geological Survey)

Throughout the past decade and more, geological surveys across the nation (and across the globe) have collaborated on geologic map database design, science terminology, and data interchange standards. Progress has been significant, and was in part facilitated by the 12 annual DMT meetings. Should we now evaluate and perhaps refine these standards, and recommend guidelines to our geological surveys?

Standards and guidelines can, together, help us deliver better and more usable geologic maps. *[See below, where standards and guidelines are defined.]* Technical standards (e.g., FGDC geologic map symbols, NADM-C1 data model, NADM-SLTT terminology, GeoSciML interchange format) are carefully defined by collaboration among experts and practitioners. These standards are "building blocks" that can be drawn together into a guideline for creating and disseminating geologic maps. Each agency then could define its own guideline, adapted to its resources and user requirements. We hope that by defining standards, and then recommending how they can be used in a guideline, there will be convergence among the geological surveys regarding creation and management of geologic databases and maps.

This session's agenda:

1. Review of geologic map standards development (especially in North America) during the past decade.
2. Request for comments, additions, corrections.
3. Presentation of "strawman" guideline, including:
   a. a minimum set of attributes for all geologic maps
   b. standard science terminologies
   c. standard stratigraphic nomenclature
   d. standard database designs
   e. a georeferenced image of the map
   f. a data-transfer standard
   g. a long-term data management plan.
4. Request for comment (e.g., concurrence, outrage, recommended changes).
5. Next steps – revise the strawman and recommend it as a guideline to AASG and USGS? To the NCGMP? Should we form a committee? Should we adjourn?

What's the difference between standards and guidelines? (adapted from Wikipedia):

- a technical standard is an established norm or requirement. It is usually a formal document that establishes uniform engineering or technical criteria, methods, processes and practices. [Worthy of note: a custom, convention, company product, corporate standard, etc. which becomes generally accepted and dominant is often called a de facto standard.]
- a guideline is any document that aims to streamline particular processes according to a set routine. By definition, following a guideline is never mandatory (protocol would be a better term for a mandatory procedure). Guidelines are an essential part of the larger process of governance. Guidelines may be issued and used by any organization (governmental or private) to make the actions of its employees or divisions more predictable, and presumably of higher quality.

Links to some standards, guidelines, and resources:

- FGDC Geologic Data Subcommittee – *http://ngmdb.usgs.gov/fgdc_gds/* (see the cartographic standard, and proposal for Standard Geologic Data Model)
- ESRI Geology Data Model – *http://support.esri.com/index.cfm?fa=downloads.dataModels.filteredGateway&dmid=30*
- NGMDB resource page for standards and guidelines – *http://ngmdb.usgs.gov/Info/standards/*
- Resources for Digital Cartography (prototype site) – *http://ngmdb.usgs.gov/Info/cartores/*

We Took a First Step in 1999

In a discussion session at DMT'99, we addressed the need for general guidelines on the files and documentation that should be included in digital map publications. That session began with a review of the newly enacted USGS publication policy for digital map products. We determined that a similar specification could be offered as a guideline to the broader community of geological surveys. The discussion went point-by-point through the draft guideline, which had been prepared by an AASG/USGS Working Group. We reached consensus in that session, and the resulting guidelines (*http://pubs.usgs.gov/of/1999/of99-386/soller2.html*) were later approved by AASG and included in the STATEMAP Request For Proposals.

The National Geologic Map Database Project – 2008 Report of Progress

By David R. Soller and Nancy R. Stamm

U.S. Geological Survey
926-A National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6977
email: *drsoller@usgs.gov*, *nstamm@usgs.gov*

Development and management of geologic map databases for support of societal decisionmaking and scientific research are critical needs. The National Geologic Mapping Act of 1992 (*http://ncgmp.usgs.gov/ncgmpabout/ngmact/ngmact1992*) and its subsequent reauthorizations mandate the 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 must 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 that requires 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.

From the guidelines in the National Geologic Mapping Act, and through extensive discussions and forums with the geoscience community and with the public, a general strategy for building the NGMDB was defined in 1995. Based on continued public input, the NGMDB has evolved from a 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 comprehensive reference tool and data management system for spatial geoscience information in paper and digital form. It consists of the following: (1) a Map Catalog containing limited metadata for all paper and digital geoscience maps and book publications that contain maps (including maps of any part of the Nation, published by any agency), online viewable images of paper and digital maps, and links to online data; (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 Congressional mandate for State-Federal collaboration has proven invaluable, facilitating progress on many technical issues that would otherwise have been much more difficult to achieve. 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). Each year in these Proceedings, and at numerous meetings and presentations, technical plans and progress are reported. 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).

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 many 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 the National Paleontology Database. ***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 will 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 Geoinformatics 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 generate 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 can be found at *http://ngmdb.usgs.gov*.

Progress in 2008

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 websites 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 2008 include:

1. Expanded Map Catalog by ~2,000 records, to a total of ~80,000 records. This includes 38,100 relevant USGS publications, 28,200 State survey publications, and 13,700 products by other publishers.
2. Engaged all States in the process of entering Map Catalog records, and processed ~1,200 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 U.S. 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. Under agreement with the USGS Publications Warehouse (PW), continued to process and serve via the Map Catalog image viewer the many thousand map images that were scanned by the PW. The agreement was undertaken to minimize duplication between the two systems, integrate them, and provide to the user the image viewer most appropriate for the publication format (MrSID format for large-format maps via NGMDB, and DjVu format for multi-page documents via PW). To increase productivity in image processing, the NGMDB purchased equipment and hired a student employee, to reside in the PW headquarters in Madison, WI.

5. Added to bibliographic records in the Map Catalog about 21,000 new links to online digital maps and reports, mostly to USGS reports served by the PW. About 40-45 percent of publications listed in the Map Catalog now have such a link; in contrast, two years ago about 13 percent of publications were linked.

6. Negotiated an arrangement to receive from the Alaska Division of Geological and Geophysical Surveys all files of USGS reports and maps of Alaska that were scanned under Federal "Data at Risk" contract funding. Files for nearly 5,000 USGS publications were received for processing and online service by NGMDB and by the PW.

7. Maintained an 8-TB computer for storage of map images and for image processing.

8. Continued to process selected NCGMP EDMAP-grant deliverables, for inclusion in the Map Catalog (e.g., *http://ngmdb.usgs.gov/Prodesc/proddesc_81551.htm*). Unpublished GIS files of these maps will be archived and password protected in the NGMDB, for later use by researchers.

9. Continued to expand and revise 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) consumed nearly all time available for this activity. As time permitted, critically important stratigraphic information (e.g., type localities) was retrieved from the authoritative published USGS lexicons (e.g., Bulletin 896) and integrated into Geolex.

10. Completed the contract scanning of all available USGS unpublished biostratigraphic reports (the Examination and Report on Referred Fossils, or "E&Rs") that in the mid-1980s had been archived on microfiche; roughly 70,000 report pages were scanned. Began to evaluate the quality of these scans, organize the reports, and record in a database the essential information from each report. To facilitate this work, a student was hired. Consolidated into a single storage facility the numerous paper copies of E&Rs, field geologists' Submittal Reports, and related files that until 1995 had been maintained by the headquarters office of the Branch of Paleontology and Stratigraphy. These paper reports and the digital information form the basis for a comprehensive NGMDB database and archive of biostratigraphic information intended for continued use by NCGMP-funded and other field mapping projects.

11. Continued to revise the Web statistics that identify the extent to which State geological survey publications are accessed via the Map Catalog. These statistics will be provided to each State geologist.

12. Customer service: Completed several hundred productive interchanges with Map Catalog and Geolex users, via the NGMDB feedback form and other mechanisms. These users vary widely in interest and background, and include school children, homeowners, local government planners, and professional geologists.

13. Gave numerous project presentations to scientists and managers at USGS, AASG, and other scientific meetings, whereby details of the project were explained and participation in building various NGMDB standards and databases was increased.

14. Worked with NCGMP to improve their data-entry procedure for Mapping in Progress database, focusing on database redesign and adding information most useful to NCGMP management.

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 non-professional 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 (e.g., 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.

Specific accomplishments in 2008 include:

1. Coordinated work on the federally endorsed (FGDC) geologic map symbolization standard, especially preparation of the printed version of the standard, and the CD-ROM and online versions of the PostScript implementation (which will be a USGS Techniques and Methods publication). Published the online version of the PostsScript implementation. Responded to numerous inquiries and comments from users of the standard.

2. Served as Chair of the FGDC Geologic Data Subcommittee. Managed the Subcommittee's website.

3. Organized and led the twelfth annual "Digital Mapping Techniques" workshop. Developed the agenda, solicited presentations, and worked to prepare the workshop proceedings. Edited and prepared for publication the workshop Proceedings from the previous year's meeting (DMT'07, Columbia, SC). These meetings have helped the geoscience community to converge on more standardized approaches for digital mapping and GIS analysis.

4. Served as committee Secretary and as member of the U.S. Geologic Names Committee.

5. Prepared a draft version of a "core" set of standards and guidelines, eventually to be submitted to the NCGMP and AASG. Convened discussion session at DMT'08 meeting to present and refine these standards (see *Summary of DMT'08 Discussion Sessions*, this volume).

6. Continued to work with ESRI regarding: (a) collaboration on an ArcGIS Geology Data Model that will be compliant with the NGMDB data model now under development, and (b) ESRI implementation of the FGDC geologic map symbolization standard. ESRI anticipates the initial release of the FGDC implementation by early 2009.

7. Served as Coordinator of the North American Geologic Map Data Model Steering Committee (NADMSC). Managed the NADM website (*http://nadm-geo.org/*).

8. Served as U.S. representative to DIMAS, the global standards body serving the Commission for the Geological Map of the World (*http://www.geology.cz/dimas*).

9. Served as the U.S. Council Member to the IUGS Commission for the Management and Application of Geoscience Information ("CGI", *http://www.cgi-iugs.org/*).

10. Participated in the IUGS CGI-sponsored "International Data Model Collaboration Working Group" (*https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/InteroperabilityWG*). Helped to develop consensus for international standards for a geologic data model. Contributed to development of the XML-format "GeoSciML" schema, which is proposed as an international data-exchange standard for geoscience information. Served as chair of Concept Definitions Working Group, and proposed initial versions of international standard science terminologies.

11. Contributed research and map data to the CGI-sponsored GeoSciML Testbed 3, which was demonstrated at the IGC2008 meeting.

12. Served as IUGS CGI liaison to the "Multi-Lingual Thesaurus Working Group." This group is enabling global exchange of geoscience information by developing a common science vocabulary that is translated into many languages.

13. Served as USGS technical representative to the international "OneGeology" project. Provided technical guidance and support to the project.

Phase Three

It is a commonly held vision that the National Geologic Map Database will be a repository of geologic map and related information, managed in a system distributed among the USGS and State geological surveys. The system would offer public access to complex, attributed vector and raster geoscience data, and allow users to perform queries, create derivative maps, and download source and derived map data. To realize this vision requires (1) 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. Phase Three is designed to foster an environment where the distributed database system can be prototyped while these requirements are being addressed by the partners.

The NGMDB is prototyping a system with two components: (1) a centralized database containing digital geologic map coverage for the U.S. at selected intermediate and small scales, and (2) distributed access to a more comprehensive set of map data held by the NGMDB collaborators (principally the State geological surveys). All information in the system would retain metadata that clearly indicates its source (e.g., who created the source map and, ideally, details on the origin and modifications to a particular contact, fault, or map unit attributes).

This is a long-term effort whose fully realized form is, at this time, difficult to predict. Because 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, the scope and details of Phase Three are systematically explored and developed through prototypes. Each prototype addresses aspects of the database design, implementation in GIS software (e.g., ArcGIS), standard science terminologies, and software tools designed to facilitate data entry. Each prototype is 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 NADM 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 is being pursued in the current 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 Map Data Portal that offers public access to a simplified view of GIS data held by various cooperating agencies.

Specific accomplishments in 2008 include:

1. Evaluation of the prototype NGMDB Map Portal in late fall 2007 indicated that changes to the Web interface, science terminologies, and map-processing workflow were necessary to provide a public website that more effectively complemented rather than competed with existing GIS map servers in the State surveys and USGS. This Portal is intended to give users a quick, integrated, browse-and-query "glimpse" of map data published by many agencies, and to direct the user to the source information. This approach is used for the Phase 1 databases (e.g., Map Catalog, Geolex), and revisions to the Portal are being made to better integrate the GIS map service with the Map Catalog and Geolex. Nearly all 2008 work on this task was directed toward cleaning up and simplifying the science terminologies and the Web interface. This decision was reached with concurrence of States participating in the prototype (Washington, Oregon, Idaho, and Arizona); addition of new map data will resume when revisions to the Portal are completed and its suitability has been assessed by NGMDB cooperators. Noteworthy tasks and accomplishments include:

    a. The preliminary standard science terminologies developed in past years were simplified and reduced in scope, to be more informative to Portal users. The preliminary terminologies will remain useful to the NGMDB and others, for more detailed geologic descriptions. The new lists are synchronized with the draft international lists developed to support GeoSciML (see oral-presentation paper by Richard and Soller, this volume).

    b. The existing terminology lists describe aspects of geologic units and materials (e.g., their lithology, age, genesis) but not the geologic units themselves. Therefore a new terminology list was developed (see Soller, this volume) to more clearly show the type of units that are mapped by geologists (e.g., "alluvium" rather than "poorly sorted clastic sediment" or "sediment of fluvial origin"). This list will promote quicker understanding of geologic map information shown in the Portal.

    c. The Portal's Web interface (adopted from the Oregon Department of Geology and Mineral Resources interface) is being extensively redesigned to address issues now deemed essential (e.g., a map legend that dynamically regenerates when the user zooms or pans, to show only those units within the field of view). This redesign is based on software technology used by the Phase 1 databases.

    d. The NGMDB Data-Entry Tool was designed to provide the project and its cooperators with an interface to manage, at an enterprise level, complex, multi-versioned geologic map data from a wide variety of sources. Development of this Tool was concluded late this year; it now supports the project's needs for data entry and database management. Funding that was directed toward this software will now be redirected to (1) refinements to the Data Portal, (2) collaborative development of database design between NGMDB and the USGS Pacific Northwest Geologic Mapping project, and (3) redesign of the entire NGMDB system as described under Phase 1, above.

2. Extensive discussions with the USGS Pacific Northwest Geologic Mapping project indicated strong agreement in the approach needed to manage geologic map information for single-map publication. Work began among the technical staff of these two projects to address and, if possible, to reconcile any differences in database design and workflow. A summary of the NGMDB project's preliminary work in this regard is found in the poster-presentation paper by Richard and Soller, this volume.

3. In order to create modern, small-scale, consistent geologic map coverage for the U.S., the NGMDB project is converting the recently published Geologic Map of North America (GMNA) to digital format (Garrity and Soller, 2008). The GIS files and metadata for the GMNA's southern sheet were completed and peer reviewed. Minor revisions to the organization of map files then were undertaken, and the map database is being prepared for USGS approval as a Data Series publication for distribu-

tion on the Web and CD-ROM. Processing of the northern sheet is underway.

4. Developed a Web service for the Geologic Map of North America. Registered it with the international OneGeology project's portal. Because of the unusual nature of the map, new technical methods were developed in order to best represent the map in OneGeology.

5. At the request of USGS Geography's National Ecosystem mapping project, the NGMDB project contributed geologic map data for integration into their national ecosystem map. This included finalizing the GIS files from the recently published map of Surficial Materials of the U.S. (*http://pubs.usgs.gov/of/2003/of03-275/*), and extensive discussions with the Ecosystem project regarding how the map should be reclassified for ecosystem mapping.

6. NGMDB staff continued to work with ESRI and others to define an ESRI Geology Data Model that is compatible with the NGMDB and GeoSciML data structures, and that can be used as an output format from the NGMDB Map Portal. This is a long and difficult process, and the NGMDB project provided some level of coordination.

Acknowledgments

We 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: Nancy Stamm (USGS, Reston; Geolex database manager and associate project chief); Alex Acosta, Dennis McMacken, Michael Gishey, Ed Pfeifer, and Jana Ruhlman (USGS, Flagstaff, Phoenix, and Tucson, AZ; Website 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); Jon Craigue (University of Arizona / USGS, Tucson, AZ; Phase 3 – data-entry tool); and David Percy (Portland State University; Phase 3 – Data Portal). We also thank the many committee members who provided technical guidance and standards (Appendix A).

References

Garrity, C.P., and Soller, D.R., 2008, DNAG Geologic Map of North America GIS: Implementation: Overview and progress, *in* D.R. Soller, ed., Digital Mapping Techniques '07 – Workshop Proceedings: U.S. Geological Survey Open-File Report 2007-1385, p. 133-136, *http://pubs.usgs.gov/of/2008/1385/pdf/garrity.pdf*.

Soller, D.R., 2005, Assessing the status of geologic map coverage of the United States—A new application of the National Geologic Map Database, *in* D.R. Soller, ed., Digital Mapping Techniques '05 – Workshop Proceedings: U.S. Geological Survey Open-File Report 2005-1428, p. 41-47, *http://pubs.usgs.gov/of/2005/1428/soller2/*.

Soller, D.R., Brodaric, Boyan, Hastings, J.T., Wahl, Ron, and Weisenfluh, G.A., 2002, The central Kentucky prototype: An object-oriented geologic map data model for the National Geologic Map Database: U.S. Geological Survey Open-File Report 02-202, 38 p., *http://pubs.usgs.gov/of/2002/of02-202/*.

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)
Warren Anderson (Kentucky Geological Survey)
Sheena Beaverson (Illinois State Geological Survey)
Elizabeth Campbell (Virginia Division of Mineral Resources)
Scott McColloch (West Virginia Geological and Economic Survey)
George Saucedo (California Geological Survey)
Loudon Stanford (Idaho Geological Survey)
Tom Whitfield (Pennsylvania Geological Survey)

DMT Listserve:
Maintained by Doug Behm, University of Alabama

IUGS Commission for the Management and Application of Geoscience Information:
Dave Soller (U.S. Geological Survey, Council Member)

Conceptual model/Interchange Task Group (of the Interoperability Working Group of the IUGS Commission for the Management and Application of Geoscience Information):
Steve Richard (Arizona Geological Survey / U.S. Geological Survey, Task Group Member)

DIMAS (Digital Map Standards Working Group of the Commission for the Geological Map of the World):
Dave Soller (U.S. Geological Survey, Working Group Member)

NGMDB contact-persons in each State geological survey:
These people help the NGMDB with the Geoscience Map Catalog and Geolex. Please see *http://ngmdb.usgs.gov/info/statecontacts.html* for this list.

These groups have fulfilled their mission and are no longer active:

NGMDB Technical Advisory Committee:
Boyan Brodaric (Geological Survey of Canada)
David Collins (Kansas Geological Survey)
Larry Freeman (Alaska Division of Geological & Geophysical Surveys)
Jordan Hastings (University of California, Santa Barbara)
Dan Nelson (Illinois State Geological Survey)
Stephen Richard (Arizona Geological Survey)
Jerry Weisenfluh (Kentucky Geological Survey)

AASG/USGS Metadata Working Group:
Peter Schweitzer (U.S. Geological Survey and Working Group Chair)
Dan Nelson (Illinois State Geological Survey)
Greg Hermann (New Jersey Geological Survey)
Kate Barrett (Wisconsin Geological and Natural History Survey)
Ron Wahl (U.S. Geological Survey)

AASG/USGS Data Information Exchange Working Group:
Dave Soller (U.S. Geological Survey and Working Group Chair)
Ron Hess (Nevada Bureau of Mines and Geology)
Ian Duncan (Virginia Division of Mineral Resources)
Gene Ellis (U.S. Geological Survey)
Jim Giglierano (Iowa Geological Survey)

AASG/USGS Data Model Working Group:
Gary Raines (U.S. Geological Survey and Working Group Chair)
Boyan Brodaric (Geological Survey of Canada)
Jim Cobb (Kentucky Geological Survey)
Ralph Haugerud (U.S. Geological Survey)
Greg Hermann (New Jersey Geological Survey)
Bruce Johnson (U.S. Geological Survey)
Jon Matti (U.S. Geological Survey)
Jim McDonald (Ohio Geological Survey)
Don McKay (Illinois State Geological Survey)
Steve Schilling (U.S. Geological Survey)
Randy Schumann (U.S. Geological Survey)
Bill Shilts (Illinois State Geological Survey)
Ron Wahl (U.S. Geological Survey)

North American Data Model Steering Committee:
Dave Soller (U.S. Geological Survey and Committee Coordinator)
Tom Berg (Ohio Geological Survey)
Boyan Brodaric (Geological Survey of Canada and Chair of the Data Model Design Technical Team)
Peter Davenport (Geological Survey of Canada)
Bruce Johnson (U.S. Geological Survey and Chair of the Data Interchange Technical Team)
Rob Krumm (Illinois State Geological Survey)
Scott McColloch (West Virginia Geological and Economic Survey)
Steve Richard (Arizona Geological Survey)
Loudon Stanford (Idaho Geological Survey)
Jerry Weisenfluh (Kentucky Geological Survey)

Appendix B. List of Progress Reports on the National Geologic Map Database, and Proceedings of the Digital Mapping Techniques Workshops

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/*.

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/*.

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/*.

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/*.

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/*.

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/*.

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/*.

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/2000/of00-325/*.

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/1999/of99-386/*.

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/1998/of98-487/*.

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/1997/of97-269/*.

Soller, D.R., 2008, The National Geologic Map Database Project – 2007 Report of Progress, *in* Soller, D.R., ed., Digital Mapping Techniques ’07 – Workshop Proceedings: U.S. Geological Survey Open-File Report 2008-1385, p. 11-20, *http://pubs.usgs.gov/of/2008/1385/pdf/soller.pdf*.

Soller, D.R., 2007, The National Geologic Map Database Project: Overview and Progress, *in* Soller, D.R., ed., Digital Mapping Techniques ’06 – Workshop Proceedings: U.S. Geological Survey Open-File Report 2007-1285, p. 7-13, *http://pubs.usgs.gov/of/2007/1285/pdf/Soller.pdf*.

Soller, D.R., Berg, T.M., and Stamm, N.R., 2005, The National Geologic Map Database Project: Overview and Progress, *in* Soller, D.R., ed., Digital Mapping Techniques ’05 – Workshop Proceedings: U.S. Geological Survey Open-File Report 2005-1428, p. 23-40, *http://pubs.usgs.gov/of/2005/1428/soller1/*.

Soller, D.R., Berg, T.M., and Stamm, N.R., 2004, The National Geologic Map Database project: Overview and progress, *in* Soller, D.R., ed., Digital Mapping Techniques ‘04—Workshop Proceedings: U.S. Geological Survey Open-File Report 2005-1451, p.15-31, *http://pubs.usgs.gov/of/2004/1451/soller/*.

Soller, D.R., and Berg, T.M., 2003, The National Geologic Map Database project: Overview and progress, *in* Soller, D.R., ed., Digital Mapping Techniques ‘03—Workshop Proceedings: U.S. Geological Survey Open-File Report 03-471, p. 57-77, *http://pubs.usgs.gov/of/2003/of03-471/soller1/*.

Soller, D.R., and Berg, T.M., 2002, The National Geologic Map Database: A progress report, *in* Soller, D.R., ed., Digital Mapping Techniques ‘02—Workshop Proceedings: U.S. Geological Survey Open-File Report 02-370, p. 75-83, *http://pubs.usgs.gov/of/2002/of02-370/soller2.html*.

Soller, D.R., and Berg, T.M., 2001, The National Geologic Map Database--A progress report, *in* Soller, D.R., ed., Digital Mapping Techniques ‘01—Workshop Proceedings: U.S. Geological Survey Open-File Report 01-223, p. 51-57, *http://pubs.usgs.gov/of/2001/of01-223/soller1.html*.

Soller, D.R., and Berg, T.M., 2000, The National Geologic Map Database--A progress report, *in* Soller, D.R., ed., Digital Mapping Techniques ‘00—Workshop Proceedings: U.S. Geological Survey Open-File Report 00-325, p. 27-30, *http://pubs.usgs.gov/of/of00-325/soller2.html*.

Soller, D.R., and Berg, T.M., 1999a, Building the National Geologic Map Database: Progress and challenges, *in* Derksen, C.R.M, and Manson, C.J., eds., Accreting the continent's collections: Geoscience Information Society Proceedings, v. 29, p. 47-55, *http://ngmdb.usgs.gov/info/reports/gisproc98.html*.

Soller, D.R., and Berg, T.M., 1999b, The National Geologic Map Database—A progress report, *in* Soller, D.R., ed., Digital Mapping Techniques '99—Workshop Proceedings: U.S. Geological Survey Open-File Report 99-386, p. 31-34, *http://pubs.usgs.gov/of/of99-386/soller1.html*.

Soller, D.R., and Berg, T.M., 1998, Progress toward Development of the National Geologic Map Database, *in* Soller, D.R., ed., Digital Mapping Techniques '98—Workshop Proceedings: U.S. Geological Survey Open-File Report 98-487, p. 37-39, *http://pubs.usgs.gov/of/of98-487/soller2.html*.

Soller, D.R., and Berg. T.M., 1997, The National Geologic Map Database—A progress report: Geotimes, v. 42, no. 12, p. 29-31, *http://ngmdb.usgs.gov/info/reports/geotimes97.html*.

Soller, D.R., and Berg, T.M., 1995, Developing the National Geologic Map Database: Geotimes, v. 40, no. 6, p. 16-18, *http://ngmdb.usgs.gov/info/reports/geotimes95.html*.

The Transition from Traditional to Digital Mapping: Maintaining Data Quality while Increasing Geologic Mapping Efficiency in Alaska

By Jennifer E. Athey, Lawrence K. Freeman, and Kenneth A. Woods

Alaska Division of Geological & Geophysical Surveys
3354 College Road
Fairbanks, AK 99709
Telephone: (907) 451-5028
Fax: (907) 451-5050
email: {*jennifer.athey*, *lawrence.freeman*, *ken.woods*}*@alaska.gov*

Introduction

The Alaska Division of Geological & Geophysical Surveys (DGGS) Mineral Resources section collects, analyzes, and publishes geological and geophysical information on Alaska's State- and Native-owned lands in order to inventory and manage Alaska's mineral resources. Knowledge of Alaska's mineral resources and framework geology is key to developing a strong mineral industry in the state, which in turn provides employment for Alaska's citizens and revenue to local governments. The Mineral Resources section typically maps and publishes at least one geologic map per year in an area of high mineral potential. In an effort to further streamline the methodology of producing these maps, the DGGS Mineral Resources section is investing in the potential for digital mapping in the field in order to create maps more efficiently. Other DGGS sections that conduct fieldwork and publish maps (Energy Resources, Volcanology, and Engineering Geology) may also adopt this technology as situations allow. DGGS anticipates that the move to digital mapping will take a number of years to fully implement and involve a few false starts. Here, we discuss the issues encountered so far and the choices made to further our objective—increased efficiency via digital mapping.

What is Digital Mapping?

Digital mapping is defined as using a computer or personal digital assistant (PDA) to record and display information that has traditionally been recorded on paper, whether on note cards, in a notebook, or on a map. Geologic mapping is an interpretive process involving multiple types of data, running the gamut from analytical data to personal observation, all synthesized and recorded by one person. With field experience over time, geologists generally develop efficient, effective personal styles of mapping with which they are comfortable. This "traditional" geologic mapping can be accomplished by a geologist almost as well in inclement weather and when surrounded by mosquitoes as in ideal conditions.

Computer technology and software are now becoming portable and powerful enough to perform some of the more mundane tasks that a geologist must do in the field, such as precisely locating oneself, simultaneously viewing multiple maps, plotting structural data, symbolizing stratigraphic units or contact types, etc. Additionally, computers can now perform some tasks that were difficult to accomplish in the field, for example, digitally recording text or voice and annotating photographs. For digital mapping to become the standard operating procedure, geologists must use the computer in the field to become more efficient, retain their effectiveness as scientists, and create a new but comfortable, personal mapping style.

Why Are We Considering Digital Mapping?

DGGS is constantly looking for ways to improve its geologic mapping workflow. In the end, given the normal, interrelated parameters of funding, available personnel, and time, we want to be as efficient as possible to produce the best possible product. We believe that digital mapping may get us closer to our goal. The main factor driving this effort is the 'time' parameter, in a number of ways.

As of 2006, geologic mapping had been completed for only about 16 percent of Alaska's 586,000-square-mile area at a scale larger than 1:250,000 (Figure 1). Due in part to the scale of available U.S. Geological Survey topographic maps as well as the coverage of existing geologic mapping, most new mapping in the lower 48 States is published at a scale on the order of 1:24,000, while new mapping in Alaska is generally published at scales of 1:50,000 or 1:63,360. At the current rate of mapping, DGGS estimates that it will take 250 years to cover the remaining State- and Native-owned bedrock areas of Alaska with 1:63,360-scale geologic maps. That daunting amount of work requires us to focus on areas with time-sensitive, high-impact value to the State, such as mineral and energy potential, hazards to citizens and infrastructure, and new transportation corridors.

Not only is there a lot of ground to cover, but a very short field season in which to map it. The optimal weather window in Alaska lasts 3 months: June, July, and August. Cold temperatures, snow cover, ice overflow in streams, and frozen ground severely hamper geologic fieldwork at other times of the year. The ever-rising cost of fieldwork also plays a large role in the amount of ground covered in a year. Since most of Alaska is inaccessible by road, helicopter transport is a necessary but expensive tool for fieldwork. Other large field expenses include helicopter fuel, fuel transport and storage, remote lodging, food and gear transportation, personnel travel, and rock sample shipments. To take advantage of the short field season and minimize field costs, DGGS typically deploys a group of five or six geologists to work in the field for up to 2 months at a time.

Timely release of data to the public, and prompt fulfillment of obligations to funding sources, are also very important. For example, the Federal STATEMAP program, one of our major funding sources for geologic fieldwork, has a turn-around time of 1 year for submitting products. With the current mapping methodology, DGGS is challenged to meet this deadline. We believe that the greatest benefit of digital mapping will be a decrease in the amount of project time necessary for data entry, potentially decreasing the overall time needed to complete a project.

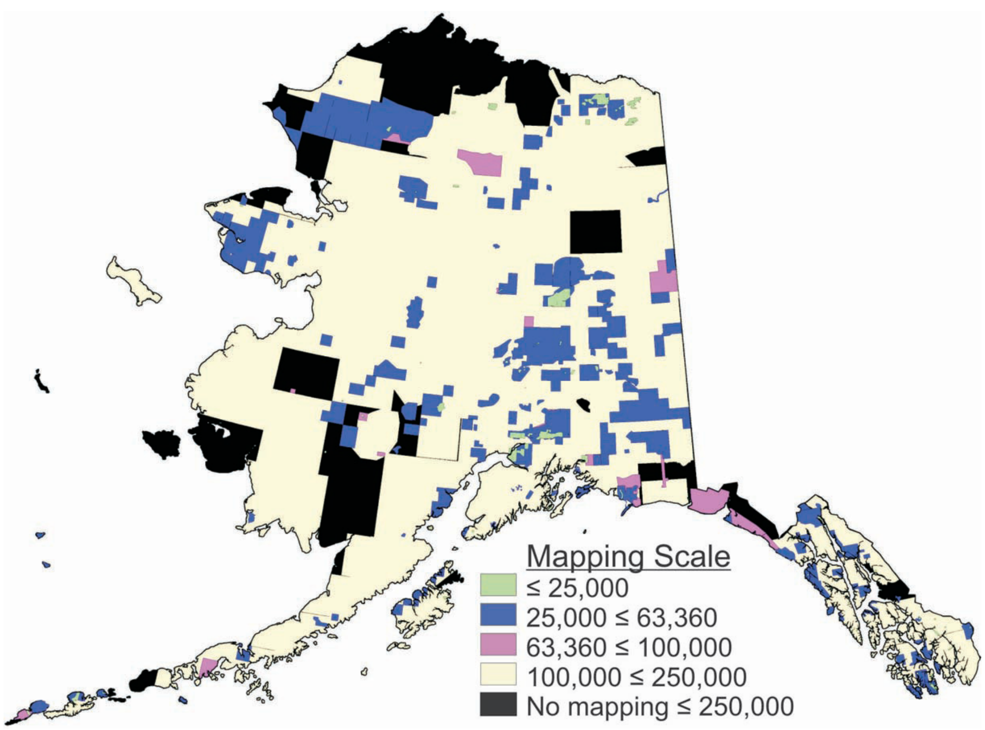


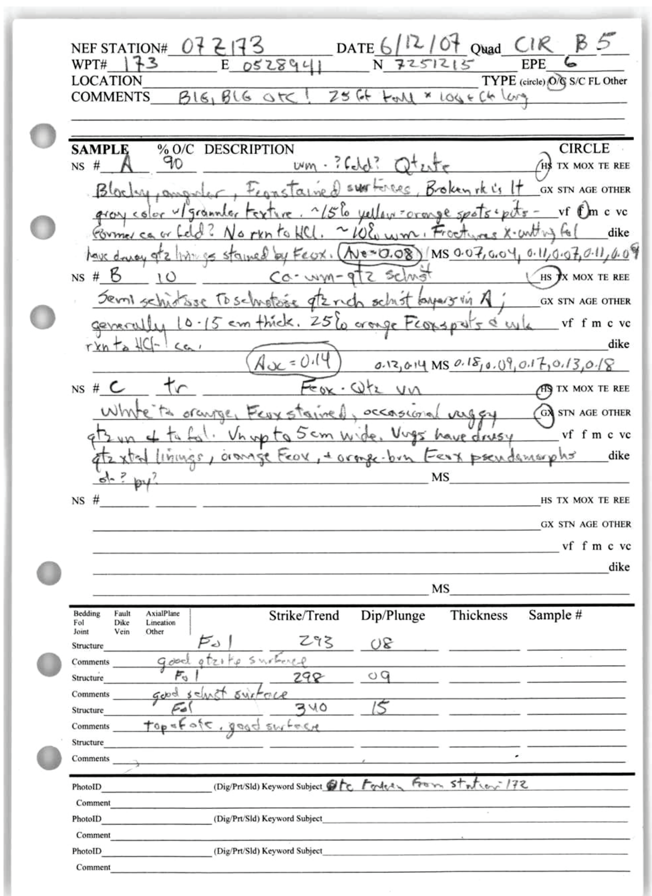
Figure 1. Map of Alaska showing status of bedrock geologic mapping at various scales as of 2006. Note: A significant portion of the Aleutian Islands is not shown on this figure. About 42% of the Aleutian Islands' land not shown (approximately 2,500 square miles) is mapped at a scale of 1:63,360 or larger, and half of their area is mapped only at a regional scale (>1:250,000).

Effects on the Geologic Mapping Process

DGGS Mineral Resources section first started looking at digital mapping in 2005 as a way to streamline the mapping process. Throughout the mapping process, digital mapping has positive and negative effects; only an assessment of its impact on the project as a whole will determine whether it is worthwhile. For simplicity, the mapping process is divided into fieldwork, data entry and basic data management, and data analysis. The current traditional methodology and digital mapping advantages and disadvantages are discussed below for each category. Particularly important advantages or disadvantages are *italicized*.

Effects on Fieldwork

Currently, DGGS Mineral Resources section employs the team model to conduct fieldwork. A crew of five or six geologists works in the same general area and compares observations nightly. Geologic observations are recorded on rain-proof (*http://www.riteintherain.com/*) standardized note cards (Figure 2) and plasticized paper maps (*http://www.igage.com/WeatherP.htm*). GPS locations are recorded on paper and saved in the GPS device. Observations are compiled by each crew member onto a single mylar basemap in the field office. No single geologist is responsible for the interpretation of an area; instead, geologic interpretations are stronger because the whole crew provides input. Project managers are responsible for arbitrating final interpretations. With the use of computers in the field, the recording of observations will change dramatically.


NEF STATION# 07Z173 DATE 6/12/07 Quad CIR B5
WPT# 173 E 0528941 N 7251215 EPE 6
LOCATION TYPE (circle) O/C S/C FL Other
COMMENTS BIG, BIG otc! 25 ft tall × 100+ ft long

SAMPLE % O/C DESCRIPTION CIRCLE
NS # A 90 wm-?feld? Qtzite HS TX MOX TE REE
Blocky, angular, Feox stained surfaces, Broken rk is lt GX STN AGE OTHER
gray color w/granular texture. ~15% yellow-orange spots & pits - vf f m c vc
former ca or feld? No rxn to HCl. ~10% wm. Fractures x-cutting fol dike
have drusy qtz linings stained by Feox. (Ave=0.08) MS 0.07, 0.04, 0.11, 0.07, 0.11, 0.09
NS # B 10 ca-wm-qtz schist HS TX MOX TE REE
Semi schistose to schistose qtz rich schist layers in A; GX STN AGE OTHER
generally 10-15 cm thick. 25% orange Feox spots & wk vf f m c vc
rxn to HCl - ca. dike
(Ave=0.14) 0.12, 0.14 MS 0.18, 0.09, 0.17, 0.13, 0.18
NS # C tr Feox-Qtz vn HS TX MOX TE REE
White to orange, Feox stained, occasional vuggy GX STN AGE OTHER
qtz vn ⊥ to fol. Vn up to 5 cm wide. Vugs have drusy vf f m c vc
qtz xtal linings, orange Feox, + orange-brn Feox pseudomorphs dike
of ? py? MS
NS # HS TX MOX TE REE
GX STN AGE OTHER
vf f m c vc
dike
MS

Bedding Fol Joint / Fault Dike Vein / AxialPlane Lineation Other	Strike/Trend	Dip/Plunge	Thickness	Sample #
Structure: Fol	293	08		
Comments: good qtzite surface				
Structure: Fol	298	09		
Comments: good schist surface				
Structure: Fol	340	15		
Comments: top of otc, good surface				
Structure				
Comments				

PhotoID (Dig/Prt/Sld) Keyword Subject Otc taken from station 172
Comment
PhotoID (Dig/Prt/Sld) Keyword Subject
Comment
PhotoID (Dig/Prt/Sld) Keyword Subject
Comment

Figure 2. Example of a completed field note card.

Advantages of Digital Mapping

- Computer screen automatically shows the location of the geologist.
- Feature data and attributes are entered directly into GIS. Features can be automatically color coded.
- Station (point) attribute data such as location, rock type, stratigraphic unit, textures, mineralogy, magnetic susceptibility, etc., are recorded directly by the geologist into a database. The geologist has total control of how the data are parsed into the database.
- Structural data are plotted automatically.
- Geologists can enter lengthy narrative descriptions into multiple data fields instead of the available free-text field, making the data more easily search-able and queryable.
- *Feature (point, line, and polygon) attributes are saved as digital text.*
- Geologists can upload each others' data files for the next day's fieldwork, for reference.
- Multiple maps and imagery (geophysics, ortho-photos, etc.) are easily carried and displayed on-screen.
- Geologists can take photographs and annotate them in the field. Photographs are immediately associated with a location.
- Hand-drawn stratigraphic sections, columns, outcrop interpretations, etc., are captured digitally. Drawings are immediately associated with a loca-tion.

Disadvantages of Digital Mapping

- Computers and related items (extra batteries, rain-proof cases, etc.) have to be carried in the field.
- Because computers are more fragile than water-proof paper, geologists have to take more care with them. (In most cases, short of a complete computer submersion in water, data can be recov-ered from the hard drive.)

- Geologists must be trained, competent, and comfortable with the hardware, software, and database.
- *Data entry into the computer by the geologist takes longer than physically writing on paper, possibly resulting in longer field programs.*
- Narratives provide detailed descriptions that are not adequately captured by the information parsed into data fields.
- Geologists may be inclined to shorten narratives because they are more difficult to enter, resulting in loss of data.
- The tremendous amount of detail present in some hand-drawn stratigraphic sections, columns, and outcrop interpretations cannot be captured by tablet-stylus entry, resulting in loss of data.
- Geologists may have a more difficult time seeing the regional perspective on a 7-inch computer screen than on larger paper maps, because panning is required.

Effects on Data Entry and Basic Data Management

DGGS Mineral Resources section currently hires student interns to perform data entry and basic data management for field projects. In the field office, the intern enters GPS data and field station data from standardized note cards into an Access database (Figure 3). The intern translates poor handwriting and abbreviations, interprets the geologic notes, and parses the data into a complicated set of database forms. It is not uncommon for data to be mistranslated or parsed into incorrect fields within the database, and these errors are difficult to identify.

Figure 3. Student intern Liping Jing downloads GPS data into the database.

In the past few years, interns have spent up to 7 months during and after the field season performing data entry. Since interpretation by the geologist must wait until data loading is completed, a long period of data entry can delay the whole project. This part of our current methodology would benefit the most from adoption of digital mapping methods.

Advantages of Digital Mapping

- *Data entry by geologists only (no student intern) takes less total time, potentially reducing the overall time needed to complete a project.*
- Data entered by geologists have fewer errors.
- Interns have additional time during the day to work with field geologists.
- Post fieldwork, interns' time is better spent gaining experience and helping with sample preparation, data analysis, and GIS.

Disadvantages of Digital Mapping

- Interns need additional training in database replication and synchronization.
- Nightly, databases need to be downloaded, synchronized, and uploaded onto field computers.
- Interns need training in GIS and operation of field computers.
- Nightly, GIS files need to be backed up from field computers, compiled, and re-uploaded.
- There are no original, hardcopy field maps or notes to archive. Paper is a more stable medium than digital format.

Effects on Data Analysis

Geologic units in Alaska are typically defined at the scale of 1:250,000. The more detailed 1:63,360-scale mapping completed by DGGS tends to delineate new lithologies (rock units with specific physical characteristics) and change previous geologic interpretations. Defining new lithologies and creating a bedrock geologic map is an iterative process requiring the spatial analysis of field data, airborne magnetics and resistivity geophysical data, geochemistry, petrography (classification of rocks by microscopic examination), age data, and other information. Mineralogical and textural data and magnetic susceptibility are queried from the database to help differentiate lithologic units (Figure 4). Digital mapping would affect when data analysis could occur, but not greatly affect the process itself.

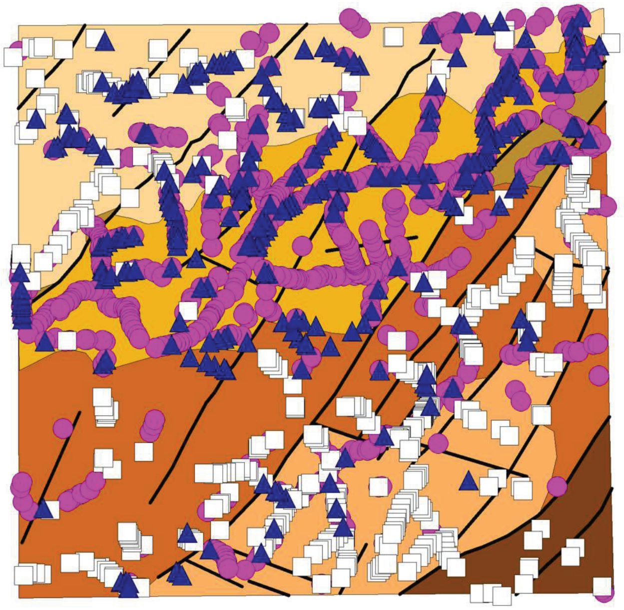


Figure 4. Data queried from the field database can be useful in differentiating lithologies. In this example, metamorphic units can largely be recognized by their relative abundance of garnet (pink circles), relict sandstone grains (white squares), and carbonate (blue triangles). Map area is about 14 by 14 miles.

Advantages of Digital Mapping

- *Analysis of field data can start immediately after returning from the field, since the database has already been populated.*
- GIS data input in the field can be directly added to the digital working copy of the map.

Disadvantage of Digital Mapping

- Data entered by multiple geologists contain more inconsistencies than data entered by one person, making the database more difficult to query.

Digital Mapping Equipment

In practice, digital geologic mappers are expensive and difficult to outfit. The initial cost of computing and supporting equipment may be significant. In addition, equipment and software must be replaced occasionally due to damage, loss, and obsolescence. Hardware and software only recently (in 2007 and 2008) became available that can satisfy most of the criteria DGGS identified in 2005 as necessary for digital mapping (Table 1). Products moving through the market are quickly discontinued as technology and consumer interests evolve. A product that works well for digital mapping may not be available for purchase the following year; however, testing multiple brands and generations of equipment and software is prohibitively expensive.

DGGS is currently field testing Samsung's Q1P SSD and Q1U-SSDXP tablet computers (*http://www.samsung.com/*), the 12-channel DeLorme Earthmate BT-20 GPS (*http://www.delorme.com/*), and the Kodak Easyshare V610 camera (*http://www.kodak.com/*; discontinued product). *(Note: Models listed are not necessarily all-inclusive of those potentially capable of meeting requirements for field entry of geologic data. Brand names are examples only and do not imply endorsement by the State of Alaska.)* The full list of gear includes the computer, two 6-cell computer batteries, stylus, computer case, sealable plastic bags, screen protector, shoulder strap, GPS with extra battery, camera, mini tripod, and other camera accessories (Figure 5). The Q1P SSD units and all supporting equipment cost $2,707 in 2007 and weigh 3.9 lb. The Q1U-SSDXP units and all supporting equipment cost $2,032 in 2008 and weigh 4.2 lb.

Software being tested includes ESRI's ArcPad 7.1.1 (*http://www.esri.com/*), Geologic Data Assistant (GDA) extension for ArcPad (Thoms and Haugerud, 2006; *http://pubs.usgs.gov/of/2006/1097/*), Microsoft's Access and OneNote (*http://office.microsoft.com/en-us/onenote/*), and EverNote's RitePen (*http://www.ritescript.com/*). ArcPad and GDA are GIS software that work together with a GPS in real time to show the geologist's current location or to digitize new features on-screen. GDA, an ArcPad extension created for geologic mapping, has been upgraded (with minor software bugs) from ArcPad 6.0.3 to version 7.1.1. DGGS is testing OneNote as a container for photographs, annotation, sketches, and narratives, and for its text recognition capability. Access houses the field database and is being tested as a field application.

Figure 5. Q1P SSD tablet and supporting digital mapping equipment.

Table 1. DGGS's digital mapping requirements for hardware and software. *Italics* indicate features not currently present in the Samsung's Q1 series tested by DGGS. Some features may be added or configured through extra hardware or software.

Essential features	Desirable features
• Intuitive to learn and easy to use. • Screen about 5" x 7"—compact but large enough to see map features. • Lightweight—must be less than 3 lb. • *Rugged* • *Waterproof* • Transcription to digital text from handwriting and voice recognition. • Can store paragraphs of data (text fields). • Can store complex databases with dropdown lists. • *Screen is easy to read in bright sunlight and on gray sky days* (could be configured). • Removable static memory cards can be used to backup data. • Chargeable by unconventional power sources (generators, solar, etc.). • Wireless real-time link to GPS. • Can change batteries in the field. • Operating system and hardware are compatible with robust GIS program.	• USB port(s) • *Case to protect from rock samples* (can be purchased separately for Q1U-SSDXP). • At least 512 MB memory. • Memory on board is recoverable. • Batteries should have no "memory," such as with lithium ion. • Wireless real-time link to computer, camera, and other peripherals. • *Portable battery with at least 9 hours of life at near constant use.* • *Real-time and post-processing differential correction for GPS locations* (could be configured).

RitePen is a "write anywhere" handwriting recognition program that allows text entry in Access forms, as well as in many other programs.

Digital Mapping Computer

Two hardware requirements stood out as particularly important for the digital mapping computer—screen size and weight. Weight, in particular, is of serious concern. At the end of a field day, DGGS minerals geologists already regularly carry 80 pounds of gear and rocks. From the computers and PDAs available in 2007, Samsung's Q1P SSD met the most requirements for our first attempt at digital mapping. Rejected options included PDAs because of their small screen size and lack of computing power, and rugged laptops and rugged tablets because of their heavier weight.

The Samsung Q1P SSD is a small but powerful tablet PC that runs Windows XP Tablet PC Edition. Its predecessor, Samsung's Q1, was one of the first Ultra-Mobile PCs (UMPC) launched in 2006 in response to Microsoft's Origami Project, which was a challenge to manufacturers to make a small, touch-screen computer, optimized for mobility (Note: Origami project closed; URL: *http://origamiproject.com* no longer operative]). Since then, Samsung has offered several redesigned iterations of the computer, two of which are the Q1P SSD (discontinued product), and the Q1U-SSDXP (or Q1 Ultra SSDXP). DGGS is currently field testing two each of these computers. Both of the UMPCs feature a 32 GB solid state (NAND flash memory) hard drive. Hence, the computer does not have a spinning hard drive, is more resistant to damage from accidental drops, and creates less heat when operating. Additionally, battery life is significantly increased because a motor is not required to constantly spin the hard drive. Both computers also have a 7-inch screen and weigh less than 2 lb with the extended 6-cell battery. See Table 2 for their specifications.

For a field computer, the biggest drawbacks of the Q1 series for DGGS purposes are their limited ruggedness and lack of waterproofing. Custom carrying cases were locally manufactured by Apocalypse Design, Inc. (*http://www.akgear.com/*) for the Q1P SSD tablets that add some protection from drops and contact with rocks. The case has a plastic shield to protect the tablet's writing surface, mesh fabric that allows air circulation, and several tabs to attach carrying straps. The Q1U-SSDXP tablets have carrying cases manufactured by OtterBox (*http://www.otterbox.com/pc-tablet-umpc-cases/samsung-q1up-case/*). The OtterBox 1990 Defender Case for Q1 Ultra UMPCs has a thermal-formed protective clear membrane to protect the writing surface, a high-impact polycarbonate shell, and a silicone layer that covers the unit and its ports. Both cases provide some water resistance but do not make the tablets waterproof.

Although inherently problematic, sealable plastic bags were determined to be the tablets' best protection against water intrusion. Concern about overheating problems due to lack of air flow in the plastic bags led to a series of heat tests. A Q1P SSD tablet was set up with a program that measures ambient air temperature, graphics processing unit (GPU) temperature, memory temperature, and CPU die-core temperature. To ensure that the computer generated the most heat possible, a process was activated that writes to and then erases 80 percent of the available memory while drawing random polygons on

Table 2. Selected specifications for the Q1P SSD and Q1U-SSDXP from *http://www.samsung.com/*.

Feature	Q1P SSD	Q1U-SSDXP
Operating system	Windows XP Tablet Edition	Windows XP Tablet Edition
Processor	Intel Pentium M ULV, 1.0 GHz	Intel Ultra Mobile Processor A110, 800 MHz
Storage	32GB SSD	32GB SSD
Memory	1GB DDRII 533	1 GB DDRII 400
Graphics	Intel® Graphics Media Accelerator 900, 128 MB	Intel® Graphics Media Accelerator 950, 128 MB
Display	7” WVGA Touch Screen LCD, 800 x 480, 280 nits	7” WSVGA Touch Screen LCD, 1024 x 600, 300 nits
Communications	802.11b/g Wi-Fi, 10/100 Base-TX Ethernet, Bluetooth 2.0	802.11 b/g Wi-Fi, 10/100 Base-TX Ethernet, Bluetooth 2.0 + EDR
Ports	Two USB 2.0, One Type II CF card, Headphone Jack, VGA	Two USB 2.0, 2-in-1 Memory Slot (SD/MMC), Headphone Jack, VGA
Dimension	9.0 x 5.5 x 1.0 inches	8.96 x 4.88 x 0.93 inches
Weight with battery	1.7 lb (with 3-cell battery)	1.4 lb (with 4-cell battery)
Keyboard	N/A	QWERTY Key Pad
Camera(s)	N/A	Front Facing Video 300 P, Rear Facing Video/Still 1.3 MP

the screen, and that uses leftover CPU cycles to compute the square root of a random 25 digit number.

The computer was placed in a sealed plastic bag, and its temperatures were monitored over the life of the standard 3-cell battery while the computer was located at room temperature and then in a 150°F oven. Then the computer was turned off, placed in its sealed bag, and chilled overnight in a –25 °F freezer. In the morning, the heat-generating processes were restarted. The computer was placed back in a sealed plastic bag and again in the oven at 150°F until the battery ran down. While the CPU did in fact slow down during these tests, it never faltered, never shut down, and never melted. The computer's self-preservation mechanism (based on temperature) slowed the processor down to slower and slower speeds in order to consume less power, thereby creating less heat.

2007 Field Test

During the summer 2007 field season, two geologists using Q1P SSD tablets tested the digital mapping equipment for 1 day. Hardware and setup issues included poor screen visibility in bright sunlight (Figure 6) and Bluetooth connection problems with the camera. It was feasible but inconvenient to cover the computer with two layers of plastic (case and sealed plastic bag) while trying to operate the buttons, and the plastic layers made screen-viewing more difficult.

In a similar field situation with Samsung Q1P series computers, Alaska Division of Forestry (DOF) field personnel had difficulty maintaining consistent Bluetooth GPS connections. DOF prefers built-in GPSs. Their temporary solution is to use external plug-in CF GPS receivers; however, field personnel have broken off two external antennas during normal use. DOF solved the screen visibility problem by replacing their computers' screens (3 Q1P and 2 rugged laptops) with Advanced Link Photonics, Inc. (*http://www.alpincorp.com/*) resistive touch transflective LCD screens (Thomas Kurkowski, oral commun., 2008). The enhanced resistive touch screens reduce glare from 10 to 20 percent on regular screens to 1 percent reflected light, and the LCD screens are transflectively

Figure 6. Surficial geologists Dick Reger (bottom left) and Trent Hubbard (under tarp) attempt to minimize screen glare and protect unit from rain while working.

upgraded and often brighter with an increase in nits by 10–30 percent (Advanced Link Photonics, Inc., oral commun., 2008).

Software issues included annoying virus software popup messages, problems recording lengthy text and with text recognition in Microsoft OneNote, and GDA incompatibility with DGGS-style field notes. In general, more time needs to be spent setting up an easy-on, automatically configured interface for field geologists so there are no or minimal technical details to manage in the field. To truly have a seamless field data entry system requires a customized, form-based, GIS-database interface.

2008 Field Test

Several personnel from DGGS Mineral Resources and Engineering Geology sections are currently testing the Q1P SSD and Q1U-SSDXP field computers. In 2008, the Access field database was replicated and placed on the tablets for direct data entry. RitePen text recognition software was provided for data entry into the Access form. Staff set up ArcPad with project GIS files to automatically load with the program, and configured GPSs with Bluetooth to provide location information to ArcPad and GDA. A Bluetooth camera was also configured to add pictures to Microsoft OneNote, where they will be annotated.

Initial impressions are that the digital mapping hardware and software were better configured this year than in 2007 but that the geologists were not adequately prepared to use the equipment. Most geologists were not familiar enough with the tablet computers, Access database, new GPSs, and how the text recognition software worked to complete meaningful field data entry. Geologists were also fearful that they would damage the hardware and were reluctant to carry it, especially in inclement weather. Thus far, positive feedback includes good performance by the RitePen text recognition software, seamless GPS connectivity via Bluetooth, good performance by the system overall as a navigational aid in the helicopter, successful capture of geologic contacts and attribute data (Figure 7), and potential use of the computer as a pocket handwarmer.

Figure 7. Geologist Trent Hubbard successfully records geologic data digitally.

Future of Digital Mapping at DGGS

Before the next field season, interested DGGS geologists will spend more time learning to use the computers and software so that they are comfortable enough with them to collect at least several days' worth of data in the field. For 2009, there will probably only be minor changes to the configuration of the computers. New daylight readable screens may be the biggest potential improvement in the system.

In the long term, some significant software changes are necessary to truly make digital mapping viable. The biggest hurdle will be creating a simple, user-friendly, form-based interface in ArcPad that can capture GIS features as well as detailed geologic data at field stations. Before that can happen, however, the Access database will need to be migrated to ESRI ArcMap (*http://www.esri.com/*), and then served out to ArcPad.

In conjunction with the move, the field database will probably be redesigned to more closely match the structure of DGGS's enterprise Oracle database (Freeman and others, 2002; Freeman and Sturmann, 2004). The redesign, development of data loading routines, and decisions about data flow and editing could start in mid-2009. To date, only station and sample field data from recent projects have been entered into the enterprise database. DGGS has had little time and no dedicated funding to perform this task. With the field database redesign, we hope that after the data have been quality controlled, it will be a fairly simple matter to load all of the data into the Oracle database.

The next step, creation of the data entry form using ESRI's ArcPad and ArcPad Application Builder (*http://www.esri.com/*), could begin in 2010. Design of the form will also require Visual Basic Scripting, possibly developed with the help of an outside contract. The interface will be designed for geologists' ease of use and could be field tested as early as 2011.

Conclusions

DGGS Mineral Resources section recognizes that the current methodology of geologic mapping can be more efficient, especially in the way field data are recorded. DGGS minerals geologists currently write field station and sample observations on note cards, which are later entered into an Access database by a student intern. In the past, data entry by student interns has taken up to 7 months. Given the limited amount of time available to complete mapping projects, this excessive period of data entry is unacceptable.

DGGS is considering digital mapping as a way to streamline the mapping process. To that end, we are evaluating the effectiveness of having geologists enter geologic observations directly into an Access database and GIS software on Samsung ultra-mobile tablet computers. Brief field tests in 2007 and 2008 suggest that the equipment and software have the potential to work as a digital mapping system but that significant work is still needed to create a system that will facilitate comfortable data entry by field geologists.

We will continue to work on new solutions and keep an eye out for new technology that will help alleviate some of the problems discovered thus far, including limited ruggedness and lack of waterproofing of the units. In the next couple of years, DGGS will train additional geologists on the computers and software so that we can then conduct more comprehensive field tests. Plans include migration of the field database to ESRI's ArcMap and ArcPad, and creating a user-friendly GIS-database data-entry interface. Through sharing ideas and results, we anticipate that it will be possible to create a DGGS-wide digital mapping system capable of benefiting all of the field projects. If the process proves effective, we anticipate that within a few years most DGGS geologists will be out on the outcrop with small field computers, happily, but more efficiently, creating geologic maps, reports, and digital data to better serve the public's needs for resource evaluation, hazards identification, and well informed land-use management.

References

Freeman, Larry, Engle, Kathryn, and Browne, Carrie, 2002, Alaska Division of Geological & Geophysical Surveys geologic database development—Logical model, *in* Soller, D.R., ed., Digital Mapping Techniques '02—Workshop Proceedings: U.S. Geological Survey Open-File Report 02-370, p. 157–160, *http://pubs.usgs.gov/of/2002/of02-370/freeman.html*.

Freeman, Larry, and Sturmann, Fred, 2004, Progress towards an agency-wide geologic map database at Alaska Division of Geological & Geophysical Surveys, *in* Soller, D.R., ed., Digital Mapping Techniques '04—Workshop Proceedings: U.S. Geological Survey Open-File Report 04-1451, p. 9–14, *http://pubs.usgs.gov/of/2004/1451/freeman/index.html*.

Thoms, E.E., and Haugerud, R.A, 2006, GDA (Geologic Data Assistant), an ArcPad extension for geologic mapping: Code, prerequisites, and instructions: U.S. Geological Survey Open-File Report 2006-1097, 23 p., *http://pubs.usgs.gov/of/2006/1097/*.

The State of the State Data: An End-User's Perspective

By Mark Zellman, David Slayter, Ranon Dulberg, Marco Ticci, Kevin Whaley, Jeff Hemphill, and Jason Finley

William Lettis and Associates, Inc.
433 Park Point Dr., Suite 250
Golden, CO 80401
Telephone: (720) 836-4891
Fax: (720) 836-4881
email: *zellman@lettis.com*

State-scale geologic data, in a format that can be used in a geographic information system (GIS), are an integral dataset for geologic consulting projects. These data, now available for each State except Alaska, often provide the best source for regional geologic coverage. State geologic maps, most commonly at 1:500,000-scale, are useful when more detailed geologic maps (ideally, 1:24,000-scale, or greater) are not available. Geologic data at a larger scale than coarsely scaled national coverage GIS geologic datasets, such as the GIS representation of King and Beikman's 1974 Geologic Map of the United States (Schruben and others, 1994; *http://pubs.usgs.gov/dds/dds11/*), provide a more useful aggregated level of detail.

The purpose of this report is to provide the end-user perspective on obtaining state-scale bedrock geologic map data. As part of our project, these map data were identified and downloaded for every State. During this process, information such as availability of metadata, symbology, source map information, and web links for where the data can be downloaded were compiled into a data sheet for every State (Appendix A); this is a catalog of what appears to be the most recent GIS database of each State's bedrock geologic map and where it can be found. We hope you will find it useful, and insightful.

There are a few options available to the end-user for finding and downloading State bedrock geology in GIS format. For individual States, data can be downloaded from State geological survey websites, U.S. Geological Survey (USGS) Open-File Reports, and certain other websites. Searching can be especially difficult when acquiring data for multiple States. The search becomes challenging because the downloading processes is often different for each State, and organizations serving the data are different from State to State. A second option for acquiring this data is through the USGS Integrated Geologic Map Databases for the United States (IGMDB; *http://pubs.usgs.gov/of/2005/1323/index_map.htm*). The IGMDB is a collection of seven USGS Open-File Reports, which group State bedrock geology by region. These data have standardized data attribute tables, metadata, and have been edge-matched along State boundaries. Through the IGMDB, bedrock geologic data are available for every State except Alaska and Hawaii. A third choice is to use the web links provided in the Geoscience Map Catalog maintained by the National Geologic Map Database (NGMDB, *http://ngmdb.usgs.gov/ngmdb/ngm_catalog.ora.html*). The NGMDB's Map Catalog is an online resource for finding and downloading geologic and geology-related maps, in paper, image, or GIS format. The NGMDB provides links to data created by the U.S. Geological Survey, State geological surveys, and other organizations that have created geologic data. The site provides access to GIS files and a scanned copy of the State geologic map for almost every State. In some cases the data record for specific States is not complete, but based on conversations with people involved with the NGMDB, they are striving to fill these gaps and provide a complete data record. Many of the gaps in NGMDB records of available data usually involve the data provided by State agencies. This is a point of concern because in some instances the GIS files from individual States are the most recent versions. Several States have revised their geologic data since the USGS IGMDB Open-File Reports were last updated.

Metadata and attribute consistency contribute greatly to the overall usefulness of any map data. Metadata provide users with important information such as an originator reference, source group or agency, date of creation, and a scale for which the maps and data are intended. For projects which adhere to strict Quality Assurance (QA) plans, if any of this information is missing or inadequate it is possible that the dataset can be regarded as unusable. For GIS data developers who utilize the Environmental Systems Research Institute's (ESRI) ArcGIS applications, it is also helpful if the GIS data are provided with metadata formatted according to existing standards such as Federal Geographic Data Committee (FGDC). This permits the metadata to be imported and viewable through ESRI's ArcCatalog and thereafter can remain with the data and be updated if they are modified, copied, or renamed. Having the metadata included with the GIS data helps to ensure that it is readily available when the data are used.

Attribute data are another important component which dictates the overall usefulness of the bedrock GIS data. A detailed attribute table changes a dataset from simply being a cartographic representation to a dataset that can be used for analysis. Basic information such as geologic unit abbreviations, geologic unit descriptions, and age should be considered minimal requirements for the attribute table. When information such as the unit description or age has not been included, the user is unable to draw much useful information from the data. Unit abbreviations and definitions, geologic age, etc., are defined as part of properly completed metadata. Another important, and often excluded, component of metadata is a full source citation. In many cases the citation for the paper source map(s) from which the shapefiles were digitized is not included in the metadata. Sometimes the citation is included but has been found to be incomplete or even incorrect. When this information is not correctly documented in the metadata of the original GIS file, this omission or error will be passed along to all subsequent derivative datasets.

Spatial reference information is provided for every bedrock geology dataset that I obtained for this study, but in some cases the spatial reference is not predefined. In these few cases the user must define the spatial reference based on information contained in the metadata or gleaned from ancillary information provided with the source data. This is generally a simple process, but the potential to incorrectly enter spatial reference information does exist. To prevent this, it would be helpful if the data being provided would have spatial reference information predefined for ArcGIS users through the use of a projection parameters file. The fields in formatted metadata exist to record spatial reference and other projection-related information.

While compiling the statewide geologic GIS files, it was found that some States have multiple versions of the statewide geology available. In many cases the State geology was mapped by two separate organizations and is made available through separate websites. Discerning which version is the "preferred," or most up-to-date, representation can often be very challenging. In many cases no documentation exists that compares the two (or more) versions. When no clear documentation is provided, or when data are being provided by two separate organizations, it is very difficult for the user to determine which dataset to use, or to understand the differences between the competing datasets.

One suggestion for making data easier to find would be to provide current links to all State geologic GIS data through a single website. This website would be updated with the most recent versions of the GIS data and maps as revisions are made to these data. This information was compiled and provided by the National Surveys and Analysis Projects: Digital State Geologic Maps, Version 1.00 web page (*http://minerals.usgs.gov/projects/surveys_and_analysis/dig_geol_maps.html*). Many of the data links are now broken or outdated; at the time of writing this summary it appears that this Web portal is no longer maintained. The NGMDB has been designed as a central hub for many kinds of geologic data. It provides links to some bedrock GIS data, but in some cases it is not the newest or preferred version**.** More recently the USGS's Mineral Resources Program has published a web page "State Geologic Maps of US States: Digital geologic maps of the US States with consistent lithology, age, GIS database structure, and format" (*http://tin.er.usgs.gov/geology/state/*). As the title indicates this page is a gateway to GIS data representing geologic features for every State. At this site, each State has its own data page that can be accessed using an intuitive interactive map interface. Each State page is loaded with data such as: links for downloading Google Earth files (.kml, .kmz) representing State geology, metadata, zipped GIS data packages, and citations for the source data. Many of the GIS files offered to the users through this gateway are links to data offered through the USGS IGMDB. This is helpful, but users might benefit if reliable links were also provided to obtain data from the individual State agencies.

Finally, the establishment of minimal requirements for metadata and attribute table completeness would be of great benefit to the data user. Setting, or suggesting, minimum requirements would help to ensure that the data download would be useful. Such information makes it possible for the user to gain information from the data rather than to simply cartographically represent the geology.

The authors would like to thank all the State agencies, federal agencies, universities, and everyone else contacted while compiling this information. Everyone I spoke with was very courteous and extremely helpful. We would have never been able to piece this compilation together without their help.

Reference

Schruben, P.G., Arndt, R.E., and Bawiec, W.J., 1994, Geology of the conterminous United States at 1:2,500,000 scale; a digital representation of the 1974 P.B. King and H.M. Beikman map: U.S. Geological Survey Digital Data Series DDS-11, 1 CD-ROM.

Appendix A. State Bedrock Geology Data Sources

EXAMPLE STATE

Agency Providing GIS data

Abstract: Provides a brief explanation of the representative geologic data in GIS format.

INFORMATION

Date Assessed: Approximate date the data were downloaded
Reference ID: Reference ID assigned by distribution agency
Projection: Defined projection of data
Scale: Largest (most detailed) scale at which data are usable
Symbology: Format and status of symbology
Metadata: Format and status of metadata

SOURCE

The citation for the source map used to create the GIS files.

WEB LINKS

GIS Data: Web link for downloading GIS data of the State's geology.

Source map: Web link for downloading a digital copy of the map that was used as the digitizing source for the GIS files. If the source map is not available, this link will be for an alternative geologic representation.

NGMDB: The web link provided in this space will take the reader to the National Geologic Map Database's page for the specified State. For most States, GIS data and a digital copy of the State geologic map may be downloaded from this link.

COMMENTS

Comments marked with a "*" are described in this section.

Alabama

Geological Survey of Alabama (GSA)

Abstract: The Geological Survey of Alabama provides State geologic data in GIS format. This dataset includes bedrock geology, fault data, dikes, map symbology and metadata. This dataset was compiled under a cooperative effort between GSA and USGS. Image files of the "Geologic Map of Alabama" can be downloaded in three parts from a University of Alabama website listed below.

INFORMATION

Date Assessed: 2/19/2008
Reference ID: Special Map 220A
Projection: NAD 1927 UTM Zone 16 N
Scale: 1:250,000
Symbology: Available as .lyr
Metadata: Available and importable

PAPER SOURCE

Szabo, E.W., Osborne, W.E., Copeland, C.W., Jr., and Neathery, T.L., 1988, Geologic map of Alabama: Geological Survey of Alabama, Special Map 220, scale 1:250,000.

WEB LINKS

GIS Data* (Last visited 1-21-2009): *http://www.ogb.state.al.us/gsa/gis_data.aspx*
Source map (Last visited 1-21-2009): *http://www.geo.ua.edu/Documentation/geology1.html*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=AL&search.x=62&search.y=13*

COMMENTS

*To find the GIS version of the Alabama geologic data, click on the link titled "Digital Geologic Map of Alabama".

Arizona

Arizona Geological Survey (AGS)
U.S. Geological Survey (USGS)

Abstract: Two versions of the digital geology of Arizona are available. The AGS provides a 1:1,000,000 scale dataset which can be purchased from their website. The USGS (USGS Open-File Report 00-409) provides 1:500,000 scale data, free of charge. GIS layer symbology is not available for the GIS files distributed by the USGS. Metadata is available for the USGS files representing Arizona geology in a format that can be imported into the GIS files.

INFORMATION

Date Assessed (AGS): 3/12/2008
Reference ID (AGS): DGM17
Projection (AGS): Lambert Conformal Conic
Scale (AGS): 1:1,000,000
Symbology (AGS): Not Available
Metadata (AGS): Not Available

Date Assessed (USGS): 3/12/2008
Reference ID (USGS): USGS Open-File Report 2000-0409
Projection (USGS): NAD 1927 Lambert Conformal Conic
Scale (USGS): 1:500,000
Symbology (USGS): Not Available
Metadata (USGS): Available in importable format

PAPER SOURCE

Arizona Geological Survey
Richard, S.M., Reynolds, S.J., Spencer, J.E., and Pearthree, P.A., 2000, Geologic map of Arizona: Arizona Geological Society, Map 35, scale 1:1,000,000.

U.S. Geological Survey
The source is the database derived from the 1983 map:
Hirschberg, D.M., and Pitts, G.S., 2000, Digital geologic map of Arizona: a digital database derived from the 1983 printing of the Wilson, Moore, and Cooper, 1:500,000-scale map: U.S. Geological Survey Open-File Report 2000-409, scale 1:500,000.

WEB LINKS

GIS Data (AGS) (Last visited 1-21-2009): *http://www.azgs.az.gov/publications.shtml*
Source map (AGS) (Last visited 1-21-2009): *http://www.azgs.az.gov/publications.shtml*

GIS Data (USGS) (Last visited 1-21-2009): *http://geopubs.wr.usgs.gov/open-file/of00-409/*
Source map (USGS) (Last visited 1-21-2009): *http://geopubs.wr.usgs.gov/open-file/of00-409/*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=AZ&search.x=50&search.y=26*

Arkansas

U.S. Geological Survey (USGS)

Abstract: GIS data representing bedrock geology of Arkansas can be downloaded through the USGS Integrated Geologic Map Database. These files were created under USGS Open-File Report 2005-1351. A digital copy (.pdf) of the 1:500,000 scale "Geologic Map of Arkansas" (Haley and others, 1993) can be downloaded from the Arkansas Geological Survey. Map symbology is not available. Metadata is provided in an importable format.

INFORMATION

Date Assessed: 2/7/2008
Reference ID: USGS Open-File Report 2005-1351
Projection: NAD 1927 Albers Conical Equal Area
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Haley, B.R., Glick, E.E., Bush, W.V., Clardy, B.F., Stone, C.G., Woodward, M.B., and Zachry, D.L., 1993, Geologic map of Arkansas: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2005/1351/*
Source map (Last visited 1-21-2009): *http://www.geology.ar.gov/sms_maps/geologic_map_arkansas.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=AR&search.x=41&search.y=8*

California

California Geological Survey (CGS)

Abstract: GIS data representing the "Geologic Map of California" (Jennings and others, 1977) can be purchased from the California Geological Survey. The data are delivered on CD, in ArcINFO export format (.e00). Included on the CD is a .TIFF copy of the Jennings and others (1977) map. Map symbology is not provided. Metadata is available, but is not provided in an importable format.

INFORMATION

Date Assessed: 2/2008
Reference ID: CD 2000-07
Projection: Lambert Conformal Conic NAD 1927*
Scale: 1:750,000
Symbology: Not Available
Metadata: Available, but not importable

PAPER SOURCE

Jennings, C.W., Strand, R.G., Rogers, T.H., Boylan, R.T., Moar, R.R., and Switzer, R.A., 1977, Geologic map of California: California Division of Mines and Geology, Geologic Data Map 2, scale 1:750,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.consrv.ca.gov/cgs/information/publications/pub_index/Pages/gis_data.aspx*
Source map (Last visited 1-21-2009):** *http://www.consrv.ca.gov/cgs/information/publications/pub_index/Pages/gis_data.aspx*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=CA&search.x=64&search.y=22*

COMMENTS

This dataset can be purchased for $30 from the State of California.

*A custom projection was created to fit the GIS files to the "irregular base" of the original published map.

**A digital copy of the State geologic map is included as a .TIFF file in the data package that can be purchased from the State geological survey.

Colorado

U.S. Geological Survey (USGS)

Abstract: Bedrock geology for Colorado can be downloaded in ArcINFO format from the USGS. These files were created under USGS Open-File Report 92-0507. A digital copy of the "Geologic Map of Colorado" can be downloaded from the Colorado Geological Survey as a .pdf.

INFORMATION

Date Assessed: 10/2007
Reference ID: USGS Open-File Report 92-0507
Projection: Lambert Conformal Conic NAD 1927
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable.

PAPER SOURCE

Tweto, Ogden, 1979, Geologic map of Colorado: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/of/1992/ofr-92-0507/*
Source map (Last visited 1-21-2009): *http://geosurvey.state.co.us/portals/0/tweto.pdf*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=CO&search.x=48&search.y=32*

Connecticut

Connecticut Department of Environmental Protection (CTDEP)

Abstract: Bedrock and Quaternary geology GIS files are available for download as shapefiles from the Connecticut Department of Environmental Protection. Symbology for the GIS files is provided as an .avl file. Metadata is available online, but is not importable.

INFORMATION

Date Assessed: 2/2008
Reference ID: Not Applicable
Projection: Connecticut State Plane Zone 3526 (feet) NAD 1983
Scale: 1:50,000
Symbology: Available as .avl
Metadata: Available, but not importable

PAPER SOURCE

Rodgers, John, 1985, Bedrock geological map of Connecticut: Connecticut Geological and Natural History Survey, Connecticut Natural Resources Atlas Series, scale 1:125000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.ct.gov/dep/cwp/view.asp?a=2698&q=322898*
Source map (Last visited 5-22-2009): See NGMDB link below

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=CT&search.x=55&search.y=21*

Delaware

Delaware Geological Survey (DGS)

Abstract: Geologic coverage for the State of Delaware is available through the USGS integrated geologic mapping project (USGS Open-File Report 2005-1325). The Delaware Geological Survey (DGS) is currently mapping and digitizing geology at a scale of 1:24,000. A digital copy of the shapefile source map (Spoljaric and Jordan, 1966) is not available, but a digital copy (.pdf) of the "Generalized Geologic Map of Delaware" (Pickett et al., 1976, Delaware Geological Survey Special Publication 9, scale 1:282,000) is available for download through DGS. Metadata is provided with the shapefile. Map symbology is not provided for the shapefile.

INFORMATION

Date Assessed: 3/12/2008
Reference ID: Open-File Report 2005-1325
Projection: NAD 1927 Lambert Conformal Conic
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Spoljaric, N., and Jordan, R.R., 1966, Delaware geological map: Delaware Geological Survey, 1966, scale 1:300,000.

WEB LINKS

GIS Data (USGS) (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2005/1325/*
Source map* (Last visited 1-21-2009): *http://www.dgs.udel.edu/publications/pubs/SpecialPublications/sp9.pdf*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=DE&search.x=58&search.y=16*

COMMENTS

*A digital copy of the source map, Spoljaric and Jordan, 1966, Delaware Geological Map, Delaware Geological Survey, 1966, 1:300,000, is not available. A generalized version of Delaware geology is available.

Florida

Florida Department of Environmental Protection

Abstract: Geologic shapefiles for Florida can be downloaded from the Florida Department of Environmental Protection's website. Data are available as polygons. A digital copy of the source paper map is also included in the download package. Layer symbology is available in .avl format. Metadata is available, but is not in a format that can be imported into the shapefile.

INFORMATION

Date Assessed: 3/12/2008
Reference ID: Map Series 146
Projection: NAD 1927 Albers Equal Area Conic
Scale: 1:750,000
Symbology: Available as .avl.
Metadata: Available, but not importable.

PAPER SOURCE

Scott, T.M., Campbell, K.M., Rupert, F.R., Arthur, J.D., Missimer, T.M., Lloyd, J.M., Yon, J.W., and Duncan, J.G., 2001, Geologic map of the State of Florida: Florida Geological Survey, Map Series 146, scale 1:750,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.dep.state.fl.us/geology/gisdatamaps/state_geo_map.htm*
Source map (Last visited 1-21-2009): *http://www.dep.state.fl.us/geology/gisdatamaps/state_geo_map.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=FL&search.x=58&search.y=23*

Georgia

Georgia GIS Clearinghouse

Abstract: Coverage files representing Georgia bedrock geology can be downloaded from the Georgia GIS Clearinghouse. This dataset is an updated version of the 1996 "Digital Geologic Map of Georgia." The download package includes faults, shear and mylonite zones, the Brevard fault zone, and dikes. A digital version of the 1976 State geologic map can be found on a personal webpage (link provided below). Layer symbology is not provided with the data. Metadata is provided, but in a format that cannot be imported into the GIS data.

INFORMATION

Date Assessed: 2/2008
Reference ID: Not Applicable
Projection: Albers Conic Equal Area NAD 1927*
Scale: 1:500,000
Symbology: Not Available
Metadata: Available, but not in importable format

PAPER SOURCE

Lawton, D.E., Moye, F.J., Murray, J.B., O'Connor, B.J., Penley, H.M., Sandrock, G.S., Marsalis, W.E., Friddell, M.S., Hetrick, J.H., Huddlestun, P.F., Hunter, R.E., Mann, W.R., Martin, B.F., Pickering, S.M., Schneeberger, F.J., and Wilson, J.D., 1976, Geologic map of Georgia: Environmental Protection Division, Georgia Department of Natural Resources, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://gis.state.ga.us/*
Source map (Last visited 1-21-2009):** *http://home.att.net/~cochran3/rocks01/ggmndx01.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=GA&search.x=56&search.y=29*

COMMENTS

*Custom projection details are explained in the metadata.

**Clicking on the map will link to higher resolution images, which can be downloaded and saved. A digital copy can also be downloaded from the NGMDB.

Hawai'i

U.S. Geological Survey (USGS)

Abstract: A USGS Open-File Report (Open-File Report 2007-1089) provides geologic data for the State of Hawai'i. GIS data are provided as Mapinfo, shapefiles, and .e00 export files. Digital copies (.pdf) of the source maps are provided in the download package. Symbology is not provided. Metadata is available and importable.

INFORMATION

Date Assessed: 3/2008
Reference ID: USGS Open-File Report 2007-1089
Projection: NAD 1983 UTM Zone 4
Scale: 1:100,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Sherrod, D.R., Sinton, J.M., Watkins, S.E., Brunt, K.M., 2007, Geologic map of the State of Hawai'i: U.S. Geological Survey Open-File Report 2007-1089, scale 1:100,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2007/1089/*
Source map (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2007/1089/*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=HI&search.x=62&search.y=24*

Idaho

Idaho Geological Survey (IGS)

Abstract: GIS files representing Idaho bedrock geology and faults can be downloaded through USGS Open-File Report 95-690 (*http://pubs.usgs.gov/of/1995/of95-690/*). These files were created from the "Geologic Map of Idaho" (Bond and others, 1978). Layer symbology is not available for these GIS files. Metadata is available but not importable. Also available is a 1:100,000 to 1:250,000 scale dataset which covers only the northern portion of the State. These files were created for USGS Open-File Report 2005-1235 (*http://pubs.usgs.gov/of/2005/1235/*). This dataset contains contacts, faults, folds, dikes, sills, veins, and geologic units. It is the preferred geologic representation for small-scale coverage.* Metadata and layer symbology are both included in the download package

INFORMATION

Date Assessed: 11/2007
Reference ID: USGS Open-File Report 95-0690
Projection: Lambert NAD 1927
Scale: 1:500,000
Symbology: Not Available
Metadata: Available but not importable

PAPER SOURCE

Bond, J.G., Kauffman, J.D., Miller, D.A., and Venkatakrishnan, Ramesh, 1978, Geologic map of Idaho: Idaho Bureau of Mines and Geology, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/of/1995/of95-690/*
Source map: A digital version does not exist. A paper copy of the Bond and Wood (1978) geologic map of Idaho (which was used to compile the GIS data, above) can be purchased from the Idaho Geological Survey.

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=ID&search.x=72&search.y=32*

COMMENTS

*The Idaho Geological Survey recommends using the USGS Open-File Report 2005-1235 as the default representation for Idaho and using the GIS version of the Bond and Wood (1978) geology as a supplement. The digital representation of Bond and Wood, 1978 provides the only full-State geologic coverage.

**A list of available geologic maps available through the IGS can be found at this link *http://www.idahogeology.org/Data/idgml.asp* (Last visited 1-21-2009).

Illinois

Illinois State Geological Survey (ISGS)

Abstract: Bedrock geology and structural features can be downloaded through the Illinois Natural Resources Geospatial Data Clearinghouse hosted by the ISGS. Shapefiles representing bedrock geology from 1967 and 2005 can be downloaded. The 2005 bedrock geology files represent revisions to the 1967 Willman and others "Geologic Map of Illinois," as made by Dennis Kolata of the ISGS. The ISGS provides a digital version (.gif) of the "Bedrock Geology of Illinois." Layer symbology is not provided. Metadata is provided and is embedded in the shapefile.

INFORMATION

Date Assessed: 2/19/2008
Reference ID: Not Applicable
Projection: GCS NAD 1983
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Kolata, Dennis, compiler, 2005, Bedrock geology of Illinois: Illinois State Geological Survey, Illinois Map Series 14, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.isgs.uiuc.edu/nsdihome/webdocs/st-geolb.html*
Source map (Last visited 1-21-2009): *http://www.isgs.uiuc.edu/nsdihome/webdocs/st-geolb.html*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=IL&search.x=30&search.y=32*

Indiana

Indiana Geological Survey (IGS)

Abstract: Bedrock geology and structural features can be downloaded as shapefiles from the Indiana Geological Survey's website. A digital copy of the source map is not available. Map symbology is not provided by IGS. Metadata is provided and is importable.

INFORMATION

Date Assessed: 2/19/2008
Reference ID: NA
Projection: NAD 1983 UTM Zone 16N
Scale: 1:500,000
Symbology: NA
Metadata: Available in downloadable format.

PAPER SOURCE

Gray, H.H., Ault, C.H., and Keller, S.J., 1987, Bedrock geologic map of Indiana: Indiana Geological Survey, Miscellaneous Map 48, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://129.79.145.7/arcims/statewide_mxd/dload_page/geology.html*
Source map (Last visited 1-21-2009): See NGMDB link below

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=IN&search.x=31&search.y=23*

Iowa

Iowa Geological Survey (IGS)

Abstract: The Iowa Geological Survey provides three representations of Iowa bedrock geology as GIS files. The "Bedrock Geology" is the GIS representation of the 1969 State geologic map. The "Geologic map of 1997" file is an updated version of the "Bedrock Geology." This version lacks geologic unit information other than an age attribute. Iowa geology is currently being remapped. Completed portions are being released in zones. The North Central (NC) and Northwest (NW) geology have been completed and are available for download. The southern segments are complete but not yet posted to the website. The NE area is being remapped. Listed below are the details for the "Bedrock Geology" (1969) dataset.

Layer symbology is not provided for the GIS file. Metadata is available in an importable format. A digital copy of the "Geologic Map of Iowa" (IGS, 1969) can be downloaded from the NGMDB. Digital copies of the updated geology are available and posted to the IGS website.

INFORMATION

Date Assessed: 2/2008
Reference ID: Not Applicable
Projection: UTM Zone 15 NAD 1983
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Iowa Geological Survey, 1969, Geologic map of Iowa: Iowa Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.igsb.uiowa.edu/nrgislibx/*
Source map (Last visited 1-21-2009): See NGMDB link below

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=IA&search.x=34&search.y=27*

COMMENTS

*A digital version of the 1969 map can be downloaded from the NGMDB. Digital versions of the revised and new geologic map segments of Iowa can be downloaded from the Iowa Geological Survey (*http://www.igsb.uiowa.edu/service/pubs.htm*). To find the data, click on "List of Publications," then from the drop-down menu select "Open File Maps (digital maps)."

Kansas

Kansas Geological Survey – Data Access and Support Center (DASC)

Abstract: Shapefiles representing surficial geology of Kansas can be downloaded through the Kansas Geological Survey's DASC. These files represent the 1:500,000 scale "Geologic Map of Kansas" (Ross, 1991). As of March, 2008, a new geologic map of Kansas is available for purchase through the Kansas Geological Survey. Currently, GIS files are not available for the 2008 version. Listed below is the information for the "Geologic Map of Kansas" (Ross, 1991).

Layer symbology is not provided. Metadata is available in an importable text format. A digital copy of the paper source map is not available.

INFORMATION

Date Assessed: 3/24/2008
Reference ID: Map M-23
Projection: Geographic NAD 1983
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Ross, J.A., 1991, Geological map of Kansas: Kansas Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009)*: *http://www.kansasgis.org/catalog/catalog.cfm*
Source map: Not Available

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=KS&search.x=47&search.y=37*

COMMENTS

*Data can be found under the "Land Surface Geology Soils" tab.

Kentucky

Kentucky Geological Survey (KGS)

Abstract: Shapefiles representing Kentucky bedrock geology, faults, karst geology, etc., can be downloaded from the Kentucky Geological Survey's website. A copy of the 1:500,000 source map is not available for download, but copies of the 1:100,000 geologic maps can be downloaded from the KGS website. Layer symbology for bedrock geology is provided in .avl format. Metadata is not provided, but was provided upon request.

INFORMATION

Date Assessed: 2/19/2008
Reference ID: Not Applicable
Projection: Geographic NAD 1983
Scale: 1:500,000
Symbology: Available as .avl
Metadata: Not Available*

PAPER SOURCE

Noger, M.C., 1988, Geologic map of Kentucky: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.uky.edu/KGS/gis/geology.htm*
Source map (Last visited 1-21-2009):** *http://www.uky.edu/KGS/mapping/100k.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=KY&search.x=42&search.y=25*

COMMENTS

*Metadata was not provided with the original download package, but was provided upon request.

**This is a link to the 1:100,000 geologic map sheets for Kentucky. The 1:500,000 map is not available for download through the State, but it can be found at the NGMDB site.

Louisiana

USGS – National Wetlands Research Center

Abstract: Geologic shapefiles for Louisiana can be downloaded through the USGS- National Wetlands Research Center. The GIS representation of bedrock geology file is provided in coverage format. This dataset was digitized from the 1984 "Geologic Map of Louisiana." Layer symbology is not provided. Metadata is provided and is importable.

INFORMATION

Date Assessed: 3/2008
Reference ID: USGS-NWRC 1984-02-0001
Projection: UTM Zone 15N NAD 1927
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Snead, J.I., and McCulloh, R.P., 1984, Geologic map of Louisiana: Louisiana Geological Survey, Geologic Map 5, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://sabdata.cr.usgs.gov/sabnet_pub/pub_sab_app.aspx?prodid=14035*
Source map (Last visited 1-21-2009): See NGMDB link below.

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=LA&search.x=80&search.y=32*

Maine

Maine Office of GIS

Abstract: Shapefiles representing bedrock and surficial geology of Maine can be downloaded from the Maine Office of GIS's website. A full size digital copy of the "Bedrock Geologic Map of Maine" (Osberg and others, 1985) can be downloaded from the Maine Geological Survey's website. GIS layer symbology is not provided. Metadata is available and is importable.

INFORMATION

Date Assessed: 2/2008
Reference ID: Not Applicable
Projection: UTM Zone 19N NAD 1983
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Osberg, P.H., Hussey, A.M., and Boone, G.M., 1985, Bedrock geologic map of Maine: Maine Geological Survey, Geologic Map Series BGMM, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009)*: *http://megis.maine.gov/catalog/*
Source map (Last visited 1-21-2009):** *http://maine.gov/doc/nrimc/mgs/explore/bedrock/index.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=ME&search.x=70&search.y=25*

COMMENTS

*On the right side of the GIS data catalog page, look for layers "Bedrock" and "surf." These are the bedrock and surficial datasets.

**To find this map, look under the "Geologic Maps" title and select "Historical Bedrock Maps of Maine – Part IV: The 1985 Bedrock Geologic Map of Maine."

Maryland

U.S. Geological Survey (USGS)
Maryland Geological Survey (MGS) and Virginia Division of Mineral Resources (VDMR)

Abstract: GIS files representing bedrock geology for Maryland were digitized from Cleaves and others (1968, Geologic Map of Maryland: Maryland Geological Survey, scale 1:250,000) under U.S. Geological Survey Open-File Report 01-187 (*http://pubs.usgs.gov/of/2001/of01-187/*). This report contains geology for the entire State of Maryland and portions of Virginia. Data for each State can be downloaded and saved separately. A digital version of the 1968 geologic map can be accessed through the Maryland Geological Survey's web page. One can access detailed segments of the geologic map by clicking on the map or on the county names on the right side of the map. GIS layer symbology is not provided in the download package. Metadata is available and importable.

INFORMATION

Date Assessed: 9/2007
Reference ID: Not Applicable
Projection: Geographic NAD 1983
Scale: 1:250,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Cleaves, E.T., Edwards, Jonathan, Jr., and Glaser, J.D., 1968, Geologic map of Maryland: Maryland Geological Survey, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2001/of01-187/*
Source map (Last visited 1-21-2009)*: *http://www.mgs.md.gov/esic/geo/index.html*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MD&search.x=58&search.y=26*

COMMENTS

*Segments of the 1968 geologic map can be downloaded by first clicking on the county of interest. This will display a county-sized portion of the 1968 map. Clicking on the map a second time will provide the user with a more "zoomed in" map image that can be downloaded. A full copy of the map can be found at the NGMDB link.

Massachusetts

Massachusetts Geographic Information System (MassGIS)

Abstract: Bedrock geology and surficial geology for Massachusetts can be downloaded from the MassGIS website. Included in the download are four symbology (.lyr) files and importable metadata. A digital image file representing the "Geologic Map of Massachusetts" can be found at the NGMDB.

INFORMATION

Date Assessed: 2/19/2008
Reference ID: NA
Projection: NAD 1983 State Plane Massachusetts Mainland FIPS 2001
Scale: 1:500,000
Symbology: Available as .lyr file
Metadata: Available and importable

PAPER SOURCE

Zen, E-an, Goldsmith, Richard, Ratcliffe, N.M., Robinson, Peter, Stanley, R.S., Hatch, N.L., Shride, A.F., Weed, E.G.A., and Wones, D.R., 1983, Bedrock geologic map of Massachusetts: U.S. Geological Survey, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.mass.gov/mgis/laylist.htm*
Source map: See the NGMDB link below.

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MA&search.x=52&search.y=14*

Michigan

Michigan Department of Natural Resources - Center for Geographic Information

Abstract: GIS files representing Michigan bedrock and Quaternary geology can be downloaded through Michigan's Center for Geographic Information. Bedrock geology can also be downloaded through the USGS Open-File Report 97-455 (*http://pubs.usgs.gov/of/1997/of97-455/*). Listed below is the information provided by the State of Michigan. A copy of the 1987 "Bedrock Geology of Michigan" can be viewed and downloaded as a .pdf from the Michigan Department of Environmental Quality. GIS layer symbology is not provided. Metadata is viewable online, but cannot be imported into the shapefile.

INFORMATION

Date Assessed: 2/2008
Reference ID: NA
Projection: Albers Conic Equal Area NAD 1983*
Scale: 1:500,000
Symbology: Not Available
Metadata: Available, but not importable

PAPER SOURCE*

Milstein, R.L., Reed, R.C., and Daniels, Jennifer, 1987, Bedrock geology of Michigan: Michigan Department of Natural Resources, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.mcgi.state.mi.us/mgdl/?action=thm*
Source map (Last visited 1-21-2009): *http://www.deq.state.mi.us/documents/deq-ogs-gimdl-MAPS.pdf*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MI&search.x=55&search.y=16*

COMMENTS

*Custom data projection details are described in the metadata.

**Compiled from three source maps. Details are available in the metadata.

Minnesota

Minnesota Geological Survey (MGS)

Abstract: GIS files representing the bedrock geology of Minnesota can be downloaded through the Minnesota Geological Survey's ftp site. The MGS provides data at a scale of 1:1,000,000. A digital version (.pdf) of the bedrock geologic map is contained in the zipped data download. GIS layer symbology is provided in .avl format. Metadata is provided, but not in a format that can be imported into a shapefile.

Based on oral communication with MGS, the State's geologic map is being updated. The map and shapefiles are expected to be released sometime in 2009.

INFORMATION

Date Assessed: 3/13/2008
Reference ID: MGS State Map Series S-20
Projection: Lambert projection std parallels 33 & 45, origin at -93 30 Long and 43 Lat
Scale: 1:1,000,000
Symbology: Available as .avl.
Metadata: Available but not importable

SOURCE

Morey, G.B., and Meints, Joyce, compilers, 2000, Geologic map of Minnesota, bedrock geology (3rd edition): Minnesota Geological Survey State Map Series S-20, scale 1:1,000,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *ftp://mgssun6.mngs.umn.edu/pub2/s-20_3ed/*
Source map (Last visited 1-21-2009)*: *ftp://mgssun6.mngs.umn.edu/pub2/s-20_3ed/*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MN&search.x=53&search.y=27*

COMMENTS

*MGS source map is contained in the zipped data available through the ftp download.

Mississippi

Mississippi Automated Resource Information System (MARIS)

Abstract: Shapefiles representing surficial geology of Mississippi can be downloaded through the MARIS website. This file represents the geology as mapped by Bicker in 1969. The data can be downloaded with one of two assigned projections: Mississippi Transverse Mercator or Geographic. GIS layer symbology is not provided. Metadata is provided but is not in an importable format. David Thompson of the Mississippi Department of Environmental Quality (MDEQ) has updated the Bicker map and shapefiles. A .pdf copy of the updated map can be downloaded from MDEQ's website. The shapefiles representing Thompson's map are not yet available to the public. A copy of the Bicker (1969) map can be downloaded from the NGMDB.

INFORMATION

Date Assessed: 2/2008
Reference ID: Not Applicable
Projection: Mississippi Transverse Mercator or Geographic
Scale: 1:500,000
Symbology: Not Available
Metadata: Available, but not importable*

PAPER SOURCE

Bicker, A.R., 1969, Geologic map of Mississippi: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.maris.state.ms.us/HTM/DownloadData/Statewide-Theme.htm*

Source map (Thompson after Bicker, 1969) (Last Visited 1-21-2009):** *http://www.deq.state.ms.us/mdeq.nsf/page/Geology_surface?OpenDocument*

Source map (Bicker, 1969) (Last visited 1-21-2009):
http://ngmdb.usgs.gov/ngm-bin/ILView.pl?sid=q500_16555_us_1.sid&vtype=b

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MS&search.x=62&search.y=19*

COMMENTS

*Metadata is available under the MARIS "Data Dictionary" link. To find the surface geology metadata click on the link for the "Data Dictionary" under the "Download Data" tab, and then choose "Physical Geography" then "Surface Geology."

**The 1969 "Geologic Map of Mississippi" by Bicker has been digitized by David E. Thompson of Mississippi Department of Environmental Quality. A digital copy of the map is available for download through the Mississippi Department of Environmental Quality.

Missouri

Missouri Spatial Data Information Service (MSDIS)

Abstract: GIS representations of Missouri geology can be downloaded from the MSDIS website. Bedrock geology, surficial geology, faults, alluvium, and other data are available in shapefile format. These GIS files were created by compiling various State geologic maps. A digital version of the map used as a source for the GIS files is not available to be downloaded. A version of the State bedrock geologic map is available through the Missouri Department of Natural Resources. GIS layer symbology is not provided. Metadata is provided and can be imported into the shapefiles.

INFORMATION

Date Assessed: 2/2008
Reference ID: Not Applicable
Projection: UTM Zone 15N NAD 1983
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Source Map: Compiled from various State geologic maps
Author: Various authors

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.msdis.missouri.edu/datasearch/ThemeList.jsp*
Source map (Last visited 1-21-2009)*: *http://www.dnr.mo.gov/geology/adm/publications/map-GenGeoMap.pdf*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MO&search.x=42&search.y=27*

COMMENTS

*This is not the source map for the Missouri bedrock GIS data. The GIS file was created by compiling various geologic maps rather than one map. This is a generalized version of the State geology.

Montana

Montana Natural Resource Information System Clearinghouse (NRIS)

Abstract: A digital representation of Montana geology was created for USGS Open-File Report 95-0691 (*http://pubs.usgs.gov/of/1995/ofr-95-0691/*). These data are also available through the NRIS. Bedrock geology, faults, dikes, and ice sheets are available for download from their website or through the USGS. A symbology (.avl) file is available through the Montana NRIS. Metadata is available and accompanies the shapefile. An image file for the "Geologic Map of Montana" (1955) is not available for download. A simplified version of the 1955 map can be found at About.com. A new geologic map of Montana was published in 2007. The "Geologic Map of Montana" (2007) is available for purchase through the Montana Bureau of Mines and Geology. A digital copy of this map is not available.

INFORMATION

Date Assessed: 2/19/2008
Reference ID: Not Applicable
Projection: Montana State Plane Single Zone NAD 1983
Scale: 1:500,000
Symbology: Available as .avl*
Metadata: Available and importable.

PAPER SOURCE

Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, Geologic map of Montana: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (NRIS) (Last visited 1-21-2009): *http://nris.state.mt.us/gis/gisdatalib/gisDataList.aspx?datagroup=statewide&searchTerms=geology*
GIS Data (USGS) (Last visited 1-21-2009): *http://pubs.usgs.gov/of/1995/ofr-95-0691/*

Source map (Last visited 1-21-2009):** See NGMDB link below
Source map (2007) (Last visited 1-21-2009)*:** *http://www.mbmg.mtech.edu/gmr/gmr-gm62.asp*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MT&search.x=72&search.y=17*

COMMENTS

*This .avl file is partially complete, and is only available if downloaded from the NRIS. The user will need to fill in some unsymbolized geologic units.

**A digital copy of Ross et al. (1955) can be downloaded from the NGMDB.

***The new "Geologic Map of Montana" (2007) can be purchased from the State geological survey.

Nebraska

University of Nebraska-Lincoln - School of Natural Resources

Abstract: GIS representations of Nebraska bedrock geology can be downloaded as Arc shapefiles from the University of Nebraska – Lincoln. This data was compiled from various geologic map sources with scales ranging from 1:250,000 to 1:1,000,000. GIS map symbology is not provided. Metadata is available, but it cannot be imported into the shapefile.

INFORMATION

Date Assessed: 3/2008
Reference ID: Not Applicable
Projection: Lambert NAD 1927
Scale: 1:1,000,000
Symbology: Not Available
Metadata: Available, but not importable

PAPER SOURCE*

Burchett, R.R., 1986, Geologic bedrock map of Nebraska: University of Nebraska Conservation and Survey Division, Geologic Maps and Charts 1, scale 1:1,000,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://snr.unl.edu/Data/NebrGIS.asp*
Source map (Last visited 1-21-2009): *http://snr.unl.edu/Data/NebrGIS.asp#BedrockGeology*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=NE&search.x=51&search.y=24*

COMMENTS

*In addition to the Burchett (1986) geologic map, various 1:250,000 geologic maps were used to create the GIS representation of the State geology. According to the metadata, the 1:250,000 maps were used for eastern and southern portions of the State, and the 1:1,000,000 geology was used for the remainder of the State.

Nevada

Nevada Bureau of Mines and Geology (NBMG)

Abstract: Two versions of geologic data for Nevada are available: USGS Open-File Report 03-66 (*http://pubs.usgs.gov/of/2003/of03-66/*) and USGS DS 249 (*http://pubs.usgs.gov/ds/2007/249/*). USGS DS 249 is the most recent version of the Nevada geologic map in digital format. Listed below are the details of the USGS DS 249 dataset. An image file for the 2007 "Geologic Map of Nevada" is not available for download. A .pdf of the "Generalized Geologic Map of Nevada" can be downloaded from the NBMG website. GIS layer symbology is provided as a .lyr file. Metadata is provided in a format that can be imported into the shapefile.

INFORMATION

Date Assessed: 2/20/2008
Reference ID: USGS DS 249
Projection: NAD 1927 UTM Zone 11 N
Scale: 1:250,000
Symbology: Available as .lyr file
Metadata: Available and importable

PAPER SOURCE

Crafford, A.E.J., and Harris, A.G., 2007, Geologic map of Nevada, *with a section on* A digital conodont database of Nevada: U.S. Geological Survey Data Series DS-249, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/ds/2007/249/*
Source map (Last visited 1-21-2009)*: *http://www.nbmg.unr.edu/dox/dox.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=NV&search.x=54&search.y=17*

COMMENTS

*A copy of the 2007 geologic map can be obtained by request. See the NGMDB link for details. This link can be used to download a generalized version of the State geology.

New Hampshire

NH GRANIT – State GIS Data Clearinghouse

Abstract: NH GRANIT provides both bedrock and surficial geologic data for the State of New Hampshire. The data can be downloaded via ftp or by requesting a CD/DVD; it is delivered in coverage format. These same files can be purchased, along with other ancillary files, from the New Hampshire Department of Environmental Services, as publication Geo-1CD. GIS layer symbology is provided for the surficial geology as a .lyr file, but is not provided for the bedrock geology. A digital copy of the "Bedrock Geologic Map of New Hampshire" (Lyons and others, 1997) can be downloaded from the NGMDB. Metadata is not available for the bedrock geology files but is provided for the surficial geology files.

INFORMATION

Date Assessed: 03.07.2008
Reference ID: Geo-1CD*
Projection / Datum: NH State Plane (feet) / NAD 1983
Scale: 1:250,000
Symbology: Not available for bedrock geology. Available for surficial geology as .lyr file
Metadata: Available**

PAPER SOURCE***

Lyons, J.B., Bothner, W.A., Moench, R.H., and Thompson, J.B., Jr., 1997, Bedrock geologic map of New Hampshire: U.S. Geological Survey, scale 1:250,000

WEB LINKS

GIS Data (Last visited 1-21-2009):
http://www.granit.unh.edu/data/downloadfreedata/category/databycategory.html#Geological%20and%20Geophysical
Source map (Last visited 1-21-2009): See the NGMDB link below.

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=NH&search.x=51&search.y=14*

COMMENTS

*Reference ID for the NH Department of Environmental Services Data package.

**Metadata for the bedrock geology is available in the form of a .pdf document and other MS Word documents, but not in an importable format. Metadata is available in an importable format for the surficial geology files.

***It appears that the shapefile representing NH State geology was originally digitized from "A New Bedrock Geologic Map of New Hampshire" (Lyons and others, 1991). This shapefile was updated in 2008 using "Bedrock Geologic Map of New Hampshire" (Lyons and others, 1997).

New Jersey

New Jersey Geological Survey (NJGS)

Abstract: Bedrock and surficial geology shapefiles can be downloaded from the New Jersey Geological Survey's website. Dikes, faults, folds, cross-sections, and topographic base are also available. An image file of the State geology is available in TIFF format and is contained in the zipped data package. GIS layer symbology is provided as an .avl file. Metadata is available, and is already attached to the shapefiles.

INFORMATION

Date Assessed: 3/6/2008
Reference ID: DGS04-6
Projection: New Jersey State Plane Coordinate System 1983 (feet)
Scale: 1:100,000
Symbology: Available as .avl
Metadata: Available and importable

PAPER SOURCE

Drake, A.A., Volkert, R.A., Monteverde, D.H., Herman, G.C., Houghton, H.F., Parker, R.A., and Dalton, R.F., 1996, Bedrock geologic map of northern New Jersey: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-2540-A, scale 1:100,000.

Owens, J.P., Sugarman, P.J., Sohl, N.F., Parker, R.A., Houghton, H.F., Volkert, R.A., Drake, A.A., Jr., and Orndorff, R.C., 1999, Bedrock geologic map of central and southern New Jersey: U.S. Geological Survey Miscellaneous Investigations Series Map I-2540-B, scale 1:100,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.state.nj.us/dep/njgs/geodata/index.htm#geology*
Source map (Last visited 1-21-2009):** *http://www.state.nj.us/dep/njgs/geodata/dgs04-6.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=NJ&search.x=48&search.y=40*

COMMENTS

**An image file (.tiff) version of the State geologic map is contained in the zipped data download.

New Mexico

New Mexico Bureau of Geology and Mineral Resources (NMBGMR)

Abstract: Geology data files representing New Mexico geology can be downloaded from the NMBGMR and through the New Mexico Resource Geographic Information System Program (NMRGIS) website. These data were created for USGS Open-File Report 97-0052 (*http://pubs.usgs.gov/of/1997/ofr-97-0052/*). A digital (.pdf) copy of the New Mexico State geologic map is contained in the USGS Open-File Report 97-0052 data download. GIS layer symbology is available through the NMRGIS data package. Metadata is available and importable.

INFORMATION

Date Assessed: 3/6/2008
Reference ID: USGS Open-File Report 97-0052
Projection: Clarke 1866 Lambert Conformal Conic
Scale: 1:500,000
Symbology: Available as .avl*
Metadata: Available as importable format

PAPER SOURCE

Anderson, O.J., and Jones, G.E., 1994, Geologic map of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-File Report 408, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009):** *http://geoinfo.nmt.edu/publications/maps/gis/home.html*
GIS Data (RGIS) (Last visited 1-21-2009): *http://rgis.unm.edu/loader_div.cfm?theme=Geology*
Source map (Last visited 1-21-2009)*:** *http://geoinfo.nmt.edu/publications/maps/gis/home.html*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=NM&search.x=36&search.y=27*

COMMENTS

*The .avl is available through the RGIS data download.

**To access the geology GIS data, click on the "OFR-97-0052" link at the bottom of the web page.

***A .pdf version of the "Geologic Map of New Mexico" is contained in the data download.

New York

New York State Museum

Abstract: Bedrock and surficial geology ArcInfo import files can be downloaded from the New York State Museum. The geologic data files are divided into several "sheets." Metadata is available for each separate sheet as a viewable .html. A digital version of the source map "Geologic Map of New York" 1970 is not available; however, a digital version of "New York State Geologic Map" from Rodgers, Isachsen, Mock, and Nahaya (1990) is available and downloadable through a Stonybrook University web link. This geologic map can also be downloaded from *http://geology.about.com* in various file sizes. GIS layer symbology is not provided.

INFORMATION

Date Assessed: 3/6/2008
Reference ID: Not Applicable
Projection: UTM Zone 18N NAD 1927
Scale: 1:250,000
Symbology: Not Available
Metadata: Available, but not importable*

PAPER SOURCE

Fisher, D.W., Isachsen, Y.W., and Rickard, L.V., 1970 Geologic map of New York State (unpublished compilation consisting of the five published sheets of the New York State Museum Map and Chart Series No. 15 [Niagara, Finger Lakes, Hudson-Mohawk, Adirondack, and Lower Hudson]), scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.nysm.nysed.gov/gis/*
Source map (Last visited 1-21-2009): *http://www.eserc.stonybrook.edu/cen514/fall2002/NYSGeologicMap.html*
Source map (Last visited 1-21-2009): *http://geology.about.com/library/bl/maps/blnewyorkmap.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=NY&search.x=27&search.y=19*

COMMENTS

* Available as viewable .html.

North Carolina

North Carolina Geological Survey (NCGS)

Abstract: Shapefiles representing geology, faults, and dikes of North Carolina can be downloaded from NC One Map. These files were created by the North Carolina Geological Survey by digitizing the 1:250,000 source maps for the 1:500,000 State geologic map. GIS layer symbology is not available to be downloaded but does exist. Metadata is provided and can be imported into the shapefile.

INFORMATION

Date Assessed: 3/2008
Reference ID: Not Applicable
Projection: NAD 1983 North Carolina State Plane FIPS 3200 (feet)
Scale: 1:250,000
Symbology: Available by request from NCGS
Metadata: Available in importable format

PAPER SOURCE

North Carolina Geological Survey, 1985, Geologic map of North Carolina: North Carolina Department of Natural Resources and Community Development, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.nconemap.com/*
Source map (Last visited 1-21-2009): *http://gis.enr.state.nc.us/sid/bin/index.plx?client=zGeologic_Maps&site=9AM*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=NC&search.x=54&search.y=27*

North Dakota

North Dakota Geographic Information Systems (ND GIS)

Abstract: North Dakota bedrock geology, surface geology, and faults can be downloaded from the ND GIS "Hub Explorer" ArcIMS website. To access and download the data, open the "Hub Explorer." Click on the "Environment" folder located on the right side of the screen. Select the layer of interest for downloading by clicking on the appropriate radio button, and then click on the "Extract Data" button located on the left side of the screen. A generalized digital version of the "Geologic Bedrock Map of North Dakota" is available from North Dakota State University. GIS layer symbology is not provided. Metadata is available in a format that can be imported into the GIS files.

INFORMATION

Date Assessed: 3/2006
Reference ID: Not Applicable
Projection: Geographic NAD 1983
Scale: 1:670,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

(Bedrock Geology)
Bluemle, J.P., 1983, Geologic and topographic bedrock map of North Dakota: North Dakota Geological Survey, Miscellaneous Map MM-25, scale 1:670,000.

(Surficial Geology)
Clayton, Lee, 1980, Geologic map of North Dakota: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.nd.gov/gis/mapsdata/int-maps.html*
Source map (Last visited 1-21-2009)*: *http://www.ndsu.edu/ndsu/nd_geology/nd_maps/nd_map1.htm*
Source map (Last visited 1-21-2009):** See NGMDB link below

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=ND&search.x=65&search.y=22*

COMMENTS

*Bedrock geology.
**Surficial geology.

Ohio

Ohio Geological Survey (OGS)

Abstract: Geologic data for the State of Ohio are available and can be purchased from the Ohio Geological Survey. The data are delivered on CD-ROM, and include bedrock geology and faults. An image file (.pdf) of the "Bedrock Geologic Map of Ohio" is also provided on the CD-ROM. This dataset can be purchased for $30. GIS layer symbology is not provided. Metadata is provided and is already imported into the geology shapefiles.

INFORMATION

Date Assessed: 3/7/2008
Reference ID: BG-1 Version 6
Projection: Ohio State Plane 1983 (feet)
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Slucher, E.R., (principal compiler), Swinford, E.M., Larsen, G.E., and others, *with GIS production and cartography by* Powers, D.M., 2006, Bedrock geologic map of Ohio: Ohio Division of Geological Survey BG-1, version 6.0, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-22-2009): *http://www.ohiodnr.com/geosurvey/pub/dms/tabid/7156/Default.aspx*
Source map (Last visited 1-22-2009)*: *http://ohiodnr.com/geosurvey/pub/maps/bgmap/tabid/7224/Default.aspx*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=OH&search.x=61&search.y=18*

COMMENTS

*A .pdf image of the State geologic map is provided on the CD-ROM.

Oklahoma

U.S. Geological Survey (USGS)

Abstract: GIS data representing faults, folds, and bedrock geology of Oklahoma can be downloaded from the USGS (*http://pubs.usgs.gov/of/2003/ofr-03-247/*). The GIS files representing State geology were created by merging twelve 1:250,000 geologic quadrangles. A digital copy (.pdf.) of the Oklahoma geologic map is provided in the download package. GIS layer symbology is not provided, however CMYK values are part of the data attribute table. Metadata is provided and can be imported into the shapefile.

INFORMATION

Date Assessed: 3/2008
Reference ID: USGS Open-File Report 03-247
Projection: Albers Conic Equal Area NAD 1983
Scale: 1:250,000
Symbology: Not Available *
Metadata: Available as importable format

PAPER SOURCE

Heran, W.D., Green, G.N., and Stoeser, D.B., 2003, A digital geologic map database for the State of Oklahoma: U.S. Geological Survey Open-File Report 03-247, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2003/ofr-03-247/*
Source map (Last visited 1-21-2009):** *http://pubs.usgs.gov/of/2003/ofr-03-247/*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=OK&search.x=68&search.y=22*

COMMENTS

*A .txt file with CMYK color values is provided.

**A digital version of the Oklahoma geologic map is packaged with the USGS Open-File Report 03-067 data.

Oregon

U.S. Geological Survey (USGS)

Abstract: USGS Open File Report 03-67 (*http://pubs.usgs.gov/of/2003/of03-067/*) provides the most current digital version of the "Geologic Map of Oregon" published by Walker and MacLeod in 1991. This Open-File Report supersedes an earlier published digital version (Raines and others, 1996; USGS DDS-41). The Open-File Report includes faults, geology, and a legend file all in ArcINFO export format. GIS layer symbology is not provided. Metadata is provided and can be imported into the GIS files.

Also available is the "Oregon Geologic Data Compilation" from DOGAMI. This dataset, not yet complete, is a compilation of the best geologic data available for the State of Oregon. It can be purchased from the "Nature of the Northwest" store for $25.

INFORMATION

Date Assessed: 03/2008
Reference ID: USGS Open-File Report 03-067
Projection: Lambert Conformal Conic NAD 1927
Scale: 1:500,000
Symbology: Not Available
Metadata: Available as importable format

PAPER SOURCE

Walker, G.W., and MacLeod, N.S., 1991, Geologic map of Oregon: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (USGS OFR 03-067) (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2003/of03-067/*
GIS Data (DOGAMI) (Last visited 1-21-2009): *http://www.naturenw.org/store-maps.htm*
Source map* (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2003/of03-067/*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=OR&search.x=84&search.y=5*

COMMENTS

*A digital version of the "Geologic Map of Oregon" is available as a .jpg, included with the USGS Open-File Report 03-067 data. O

Pennsylvania

Pennsylvania Department of Conservation and Natural Resources (PA DCNR)

Abstract: Geology shapefiles can be downloaded from the PA DCNR's Geological Survey website. Available files include bedrock geology, and dikes. GIS layer symbology is provided as a .style file. Metadata is provided as .html but is not importable into the GIS files.

INFORMATION

Date Assessed: 3/13/2008
Reference ID: Not Applicable
Projection: Geographic NAD 1927
Scale: 1:250,000
Symbology: Available as .style files
Metadata: Available as .htm format – Not importable

PAPER SOURCE

Berg, T.M., Edmunds, W.E., Geyer, A.R., Glover, A.D., Hoskins, D.M., MacLachlan, D.B., Root, S.I., Sevon, W.D., and Socolow, A.A., 1980, Geologic map of Pennsylvania: Pennsylvania Geological Survey, Map 1, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.dcnr.state.pa.us/topogeo/gismaps/geomaps.aspx*
Source map* (Last visited 1-21-2009): *http://www.dcnr.state.pa.us/topogeo/maps/map7.pdf*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=PA&search.x=43&search.y=32*

COMMENTS

*This is a generalized (page sized) version of the "Geologic Map of Pennsylvania." See the NGMDB link for a digital copy of the Berg et al. (1980) map.

Rhode Island

Rhode Island Geographic Information System (RIGIS)

Abstract: RIGIS provides bedrock geology for the State of Rhode Island in both ArcInfo export and shapefile format. This shapefile reflects the updates to the 1971 "Rhode Island Geologic Map." A digital copy of the "Bedrock Geologic Map of Rhode Island" can be downloaded at the link below. GIS layer symbology is not provided. Metadata is available and can be imported into the GIS files.

INFORMATION

Date Assessed: 3/6/2008
Reference ID: Not Applicable
Projection: Rhode Island State Plane 3800 (feet) NAD 1983
Scale: 1:100,000
Symbology: Not Available
Metadata: Available as importable format

PAPER SOURCE

Hermes, O.D., Gromet, L.P., Murray, D.P., Hamidzada, N.A., Skehan, J.W., and Mosher, S., 1994, Bedrock geologic map of Rhode Island: Rhode Island Geological Survey, Rhode Island Map Series Map 1, scale 1:100,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.edc.uri.edu/rigis/data/geoscientificInformation.aspx*
Source map (Last visited 1-21-2009): *http://geology.about.com/library/bl/maps/blrhodeislandmap.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=RI&search.x=72&search.y=26*

South Carolina

U.S. Geological Survey (USGS)
South Carolina Department of Natural Resources (SCDNR)

Abstract: USGS Open-File Report 01-298 provides bedrock geology for the Appalachian Piedmont and Blue Ridge region of South Carolina at a scale of 1:500,000. The South Carolina Department of Natural Resources (SCNDR) provides generalized geology for the entire State. This version is not available in GIS format. GIS layer symbology is not provided for any of the GIS files. Metadata is available for all GIS data and can be imported into the GIS files.

INFORMATION

USGS
Date Assessed: 3/11/2008
Reference ID: Open-File Report 01-298 (USGS data)
Projection (USGS): Lambert Conformal Conic
Scale (USGS): 1:500,000
Symbology: Not Available
Metadata (USGS): Available as an importable format

SCDNR
Date Assessed: 3/11/2008
Reference ID: Not Applicable
Projection (SCDNR): NAD 1927 UTM Zone 17N
Scale (SCDNR): 1:1,000,000
Symbology: Not Available
Metadata (SCNDR): Available, already imported into shapefile.

PAPER SOURCE

(USGS – Appalachian region only)
Horton, J.W., Jr., and Dicken, C.L., 2001, Preliminary digital geologic map of the Appalachian Piedmont and Blue Ridge, South Carolina segment: U.S. Geological Survey Open-File Report 01-298.

(SCDNR – Full State coverage)
Maybin, A.H., III, and Nystrom, P.G., Jr., 1995, Geological map of South Carolina: South Carolina Geological Survey, General Geologic Map Series GGMS-1, scale 1:1,000,000.

WEB LINKS

GIS Data (USGS) (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2001/of01-298/*
Source map (USGS) (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2001/of01-298/*

GIS Data (SCNDR) (Last visited 1-21-2009): *http://www.dnr.sc.gov/GIS/gisdnrdata.html*
Source map (SCDNR) (Last visited 1-21-2009): *http://www.dnr.sc.gov/geology/geology.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=SC&search.x=54&search.y=14*

South Dakota

South Dakota Geological Survey

Abstract: A GIS representation of the "Geologic Map of South Dakota" (2004) can be downloaded from the South Dakota Geological Survey's website. The shapefile and corresponding map represent surficial geology for the entire State. Bedrock geology is available for the eastern part of the State, east of the Missouri River. GIS layer symbology is available as a .lyr files for both the surficial and bedrock geology. Metadata is available in a .pdf document and cannot be imported into the GIS data files.

INFORMATION

Date Assessed: 4/2008
Reference ID: General Map No. 10
Projection: Custom – NAD 1927 Lambert Conformal Conic (feet)
Scale: 1:500,000
Symbology: Available as .lyr
Metadata: Available but not importable*

PAPER SOURCE

Martin, J.E., Sawyer, J.F., Fahrenbach, M.D., Tomhave, D.W., and Schulz, L.D., 2004, Geologic map of South Dakota: South Dakota Geological Survey, Map 10, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009):** *http://www.sdgs.usd.edu/*

Source map (Last visited 1-21-2009):** *http://www.sdgs.usd.edu/printedpubmaps/index.html*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=SD&search.x=42&search.y=25*

COMMENTS

*A .pdf document is available. The document contains reference data, but it does not contain source, scale, or projection information.

**On the home page click on "Publications & Maps." On the next page in the top right click on "Download Publications & Maps." On the third page under "Map Series," click on "General." Scroll to the bottom of the fourth page to find shapefiles and digital copies of the bedrock (G-09) and surficial (G-10) maps.

Tennessee

Tennessee Spatial Data Server

Abstract: Shapefiles representing Tennessee geology are available through the USGS Water Resources NSDI Node. These files are downloadable in coverage format. Please note that the Tennessee Spatial Data Server, the site from which this data was downloaded, states that the Tennessee Division of Geology does not endorse this coverage, as this version is still incomplete and not fit for distribution. GIS layer symbology is not provided. Metadata is included as a text document and cannot be imported into the GIS files.

INFORMATION

Date Assessed: 3/6/2008
Reference ID: NA
Projection: Geographic NAD 1983
Scale: 1:250,000
Symbology: Not Available
Metadata: Available but not importable

PAPER SOURCE*

Miller, R.A., Hardeman, W.D., and Fullerton, D.S., 1966, Geologic map of Tennessee [West Sheet]: Tennessee Division of Geology, State Geologic Map SWS, scale 1:250,000.

Miller, R.A., Hardeman, W.D., Fullerton, D.S., Sykes, C.R., and Garman, R.K., 1966, Geologic map of Tennessee [West Central Sheet]: Tennessee Division of Geology, State Geologic Map SWC, scale 1:250,000.

Swingle, G.D., Hardeman, W.D., Fullerton, D.S., Sykes, C.R., and Miller, R.A., 1966, Geologic map of Tennessee [East Sheet]: Tennessee Division of Geology, State Geologic Map SES, scale 1:250,000.

Swingle, G.D., Miller, R.A., Luther, E.T., Hardeman, W.D., Fullerton, D.S., Sykes, C.R., and Garman, R.K., 1966, Geologic map of Tennessee [East Central Sheet]: Tennessee Division of Geology, State Geologic Map SEC, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.tngis.org/geology.html*
Source map (Last visited 1-21-2009): See the NGMDB link below

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=TN&search.x=68&search.y=21*

COMMENTS

*This shapefile was compiled from four separate geologic map sheets.

Texas

U.S. Geological Survey (USGS)

Abstract: GIS data representing the bedrock geology and faults of Texas can be downloaded as USGS DS-170. The files are available as ArcINFO coverages and shapefiles. GIS layer symbology is not provided. Metadata is provided in a format that can be imported into the GIS files. A digital copy of the map used to create the GIS files is included in the data package as four separate .pdf documents.

INFORMATION

Date Assessed: 4/1/2008
Reference ID: USGS DS 170
Projection: NAD 1927 Lambert Conformal Conic
Scale: 1:500,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Barnes, V.E. (project supervisor), 1992, Geologic map of Texas: University of Texas at Austin, Bureau of Economic Geology, Map SM-0003, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/ds/2005/170/*
Source map (Last visited 1-21-2009)*: *http://pubs.usgs.gov/ds/2005/170/*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=TX&search.x=74&search.y=20*

COMMENTS

*A digital (.pdf) representation of the geologic map is included in the USGS data package as four separate map sheets.

Utah

Utah Geological Survey (UGS)

Abstract: GIS geologic map data (bedrock geology and faults) can be downloaded from the Utah Geological Survey as shapefiles. UGS provides a digital (.pdf) version of the State geologic map. GIS layer symbology is provided as a .lyr file. Metadata is provided in a format that can be imported into the GIS data files.

INFORMATION

Date Assessed: 3/13/2008
Reference ID: Not Applicable
Projection: NAD 1927 UTM Zone 12 N
Scale: 1:500,000
Symbology: Available as .lyr
Metadata: Available and importable*

PAPER SOURCE

Hintze, L.F., Willis, G.C., Laes, D.Y.M., Sprinkel, D.A., and Brown, K.D., 2000, Digital geologic map of Utah: Utah Geological Survey, Map 179DM, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://geology.utah.gov/maps/gis/index.htm*
Source map (Last visited 1-21-2009): *http://geology.utah.gov/maps/geomap/statemap/index.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=UT&search.x=59&search.y=28*

COMMENTS

*Importable metadata is provided as a .MET file. To make this file importable, the user must delete "Metadata:" and the next blank line and then save as .txt.

Vermont

U.S. Geological Survey (USGS)

Abstract: GIS files representing bedrock geology and faults of Vermont can be downloaded through U.S. Geological Survey Open-File Report 2006-1272. GIS layer symbology is not provided. Metadata is provided and can be imported into the GIS files.

INFORMATION

Date Assessed: 3/11/2008
Reference ID: Open-File Report 2006-1272
Projection: Vermont State Plane Meters (NAD83)
Scale: 1:250,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Doll, C.G., Cady, W.M., Thompson, J.B., and Billings, M.P., 1961, Centennial geologic map of Vermont: Vermont Geological Survey, Miscellaneous Map MISCMAP-01, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://pubs.usgs.gov/of/2006/1272/*
Source map (Last visited 1-21-2009)*: *http://www.anr.state.vt.us/dec/geo/centmap.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=VT&search.x=60&search.y=20*

COMMENTS

* The "Centennial Geologic Map of Vermont" (Doll, 1961) can be viewed at the Vermont Geological Survey's website. A digital copy can be downloaded from the NGMDB.

Virginia

Virginia Department of Mines, Minerals, and Energy (DMME)

Abstract: Both shapefiles and a paper copy of the 1:500,000 Geologic Map of Virginia can be purchased from the Virginia Department of Mines, Minerals, and Energy. GIS layer symbology is not provided in the data package for sale but does exist. Metadata is provided in a format that can be imported into the GIS files.

INFORMATION

Date Assessed: 3/11/2008
Reference ID: Publication 174
Projection: Geographic NAD 1927
Scale: 1:500,000
Symbology: Available, but not included on disc. Need to contact VA DMME for .lyr file.*
Metadata: Available and importable

PAPER SOURCE

Virginia Division of Mineral Resources, 1993, Geologic map of Virginia: Virginia Division of Mineral Resources, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *https://www.dmme.virginia.gov/Commerce/ProductDetails*.aspx?ProductID=1286
Source map (Last visited 1-21-2009): *https://www.dmme.virginia.gov/Commerce/ProductDetails*.aspx?ProductID=1280

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=VA&search.x=49&search.y=23*

COMMENTS

A 1:500,000-scale geologic paper map and shapefiles are available from Virginia Department of Mines Minerals and Energy for purchase for $15.

*Map symbology is not included on the disc, but I was able to obtain these data by calling DMME.

Washington

Washington State Department of Natural Resources, Division of Geology and Earth Resources

Abstract: Two datasets are available which represent the geology for the State of Washington. USGS Open-File Report 95-684 (*http://pubs.usgs.gov/of/1995/of95-684/*) provides geology and faults in coverage format at a scale of 1:1,000,000. Washington State DNR provides geologic shapefiles at a scale of 1:100,000. Both datasets provide digital (.pdf) versions of the State geology map. GIS layer symbology is not provided with the DNR data. Metadata is provided for the DNR data and can be imported into the GIS files.

Listed below is information for the Washington State DNR data files.

INFORMATION

Date Assessed: 3/13/2008
Reference ID: GM-53
Projection: NAD 1983 HARN State Plane Washington South FIPS 4602 (feet)
Scale: 1:100,000
Symbology: Not Available
Metadata: Available and importable

PAPER SOURCE

Washington Division of Geology and Earth Resources, 2005, Digital 1:100,000-scale geology of Washington State, version 1.0: Washington Division of Geology and Earth Resources, Open File Report 2005-3, scale 1:100,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *http://www.dnr.wa.gov/ResearchScience/Topics/GeologyPublicationsLibrary/Pages/pub_ofr05-3.aspx*
Source map (Last visited 1-21-2009)*: *http://www.dnr.wa.gov/Publications/ger_publications_list.pdf*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=WA&search.x=53&search.y=26*

COMMENTS

*Select publication GM-5.

West Virginia

West Virginia GIS Technical Center

Abstract: GIS representations of bedrock geology and faults of West Virginia can be downloaded from the West Virginia GIS Technical Center. GIS layer symbology is not provided. Metadata is available, but it is not in a format that can be imported into the shapefile. A digital copy of the "Geologic Map of West Virginia" (Cardwell and others, 1968) is not available. A generalized geologic map of the State can be downloaded from the link below.

INFORMATION

Date Assessed: 4/1/2008
Reference ID: Not Applicable
Projection: NAD 1983 UTM Zone 17N
Scale: 1:250,000
Symbology: Not Available
Metadata: Available but not importable*

PAPER SOURCE

Cardwell, D.H., Erwin, R.B., and Woodward, H.P., 1968, Geologic map of West Virginia: West Virginia Geological and Economic Survey, Map 1, scale 1:250,000.

WEB LINKS

GIS Data (Last visited 1-21-2009):** *http://wvgis.wvu.edu/data/data.php*
Source map (Last visited 1-21-2009): See the NGMDB link below

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=WV&search.x=47&search.y=25*

COMMENTS

*Metadata is viewable on the download page.

**To find the data, select "geology" as the subject to search.

Wisconsin

Wisconsin Geological and Natural History Survey (WGNHS)
U.S. Geological Survey (USGS)

Abstract: Two versions of the GIS files representing the bedrock geology of Wisconsin are available. These files can be obtained from the Wisconsin Geological and Natural History Survey (WGNHS) or the USGS. The files provided by the WGNHS, at a scale of 1:1,000,000, are from Mudrey and others (1982, Bedrock geologic map of Wisconsin). U.S. Geological Survey Open-File Report 97-455 version 3, November 1999 (*http://pubs.usgs.gov/of/1997/of97-455/*) has reinterpreted bedrock geology for Wisconsin and provides data at a scale of 1:500,000. The WGNHS dataset provides shapefiles as well as a georeferenced image file of the State geology. The USGS dataset (Open-File Report 97-455) includes GIS data for Minnesota, Wisconsin, and Michigan. Bedrock geology and fault data are available in ArcInfo coverage format. GIS layer symbology is not available from either location. Metadata is available and importable.

INFORMATION

Date Assessed: 4/1/2008
Reference ID: State Map 18
Projection: Custom – Transverse Mercator NAD 1983 HARN*
Scale: 1:1,000,000
Symbology: Not Available
Metadata: Available as importable format

PAPER SOURCE**

Mudrey, M.G., Jr., Brown, B.A., and Greenberg, J.K., 1982, Bedrock geologic map of Wisconsin: Wisconsin Geological and Natural History Survey, State Map 18, scale: 1:1,000,000

WEB LINKS

GIS Data (Last visited 1-21-2009)*:** *http://www.uwex.edu/wgnhs/gis.htm*
Source map (Last visited 1-21-2009)**:** *http://www.uwex.edu/wgnhs/gis.htm*

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=MI&State=WI&search.x=55&search.y=21*

COMMENTS

*Specific projection details can be found in the metadata.

**This is the paper source for the version of Wisconsin bedrock geology being provided by WGNHS.

***Scroll to the bottom of the "WGNHS publications containing geologic maps" page to find the link to download the files for statewide geology.

****A digital copy of the State geologic map is contained in the WGNHS data package.

Wyoming

Wyoming Geographic Information Science Center (WyGISC)

Abstract: Wyoming geologic data can be downloaded from both WyGISC and the USGS (*http://pubs.usgs.gov/of/1994/ofr-94-0425/*). WyGISC provides bedrock geology, surficial, and fault/dike data through the Wyoming GeoLibrary (*http://www.wygisc.uwyo.edu/geolibrary/*). The data provided by WyGISC are an updated and modified version of the USGS data. These shapefiles are based on the 1985 Love and Christiansen map. GIS layer symbology is not provided. Metadata is available in a format that can be imported into the GIS files. A digital copy of this map can be downloaded from the NGMDB.

INFORMATION

Date Assessed: 3/12/2008
Reference ID: Not Applicable
Projection: Geographic NAD 1983
Scale: 1:500,000
Symbology: Not available
Metadata: Available and importable

PAPER SOURCE

Love, J.D. and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey, scale 1:500,000.

WEB LINKS

GIS Data (Last visited 1-21-2009): *ftp://piney.wygisc.uwyo.edu/data/geology/bedgeol.zip*

Source map (Last visited 1-21-2009): See the NGMDB link below

NGMDB (Last visited 5-22-2009): *http://ngmdb.usgs.gov/ngm-bin/ngm_search_dbi.pl?src_page=ngm_SMsearch.html&geologictheme=stmap&State=WY&search.x=70&search.y=28*

Rescuing Legacy Digital Data: Maps Stored in Adobe Illustrator™ Format

By Andrew L. Wunderlich and Robert D. Hatcher, Jr.

Tectonics and Structural Geology Research Group
Department of Earth and Planetary Sciences
and Science Alliance Center of Excellence
306 Earth and Planetary Sciences Building
1412 Circle Drive
University of Tennessee
Knoxville, TN 37996-1410
Telephone: (865) 974-6448
email: *gibbon@utk.edu*

Abstract

As GIS databases become a standard for spatial data storage, many organizations may be struggling to integrate "legacy" digital data into modern geospatial databases. Map information that is stored in older digital data formats without spatial reference or attribution are in danger of being lost for future mapping and analysis purposes if the data are not converted to a newer digital geospatial database. One popular digital file type for mapping is the Adobe Illustrator™ (AI) format. In our research group at the University of Tennessee, we have a large collection of legacy digital and paper geologic maps covering over 100 7.5-minute quadrangles, which are products of over 40 years of detailed geologic mapping (1:24,000 or larger scale) mostly in the southern Appalachians. Our goal is to transform these data into geospatial databases to enhance their long-term survival and to make them more useful to the geologic community. In response, a six-step method has been developed to convert these maps, virtually intact, to the ESRI geodatabase format: (1) the original files are organized into layers and cleaned up in AI and exported as AutoCAD™ drawings; (2) AutoCAD files are converted to shapefiles and spatially adjusted in ArcMap™ and appended into a geodatabase; (3) geologic point data attributes that were not retained directly are either calculated from the feature (strike/rotation) or added to the features semi-automatically with the help of ArcMap utilities developed in-house (dip/plunge); (4) the entire database is then checked for topology errors, and if the map being processed is adjacent to existing map databases, the adjoining edges are reconciled; (5) quality control (QC) measures are taken, including correcting mistaken attribution; and (6) the finished database is then symbolized, labeled in ArcMap, and exported as a graphic for placement in a final map layout for editing and publication. This is a working method, and as such we are interested in suggestions for improvements.

Introduction

Many geoscience organizations have large collections of legacy maps in their possession. These maps may be in paper, stable base (Mylar), or other analog forms, or they may be stored in one of various digital formats. Most of these maps were produced for publication and usually have no digital geospatial component, unless they have been digitized. Maps may also be stored in such legacy digital graphics formats as Adobe Illustrator, Macromedia Freehand (no longer in production), and CorelDraw. These formats are common, because these programs have been the best computer graphics solutions for preparing maps to be published. While printed maps are still the standard for many organizations, new technology being utilized in the capture and storage of geospatial data, such as GPS data logging, has created the need to develop geospatial databases in which to store this content. Now, many people are struggling with this duality–new data are stored in databases, old data are stored on paper or in digital graphics–and the two are not easily integrated. Geologic maps stored in legacy digital formats have the potential to be converted to newer geospatial databases. The time, effort, and cost to do research, collect data, and create and edit these maps certainly justify the comparatively small cost to convert these data to modern formats that are accessible through GIS software and are thus interoperable with new datasets.

Conversion of maps in legacy formats has been the topic of several past DMT presentations. Hatcher (2005, p. 11) wrote of the importance of converting old maps to digital formats. He stated that old maps are still a vital source of "primary geometric, spatial, and resources data useful for crustal and surficial geologic research, and mining, petroleum, engineering, and environmental applications." He describes the process of scanning and re-compiling old maps in Adobe Illustrator, using the third-party extension MAPublisher by Avenza to georegister the content. The use of MAPublisher to manage the map content has the advantage of being able to export shapefiles of the features to be used in a GIS. However, this method relies on an expensive third-party application to export map data for use in GIS, and the management of geospatial data in Illustrator is not ideal, because that is not its intended use. GIS software packages, such as ArcGIS, are designed for creating, managing, and analyzing geospatial data, and, with recent improvements to the cartographic capabilities, are better equipped to produce maps that are of publication quality, at a price comparable to that of a single-user license for MAPublisher. As a result, more and more organizations are turning to GIS software for creating new geologic datasets and maps, as well as integrating old data and maps through digitization. But the issue of how to integrate legacy digital formats persists. At the Digital Mapping Techniques '06 meeting, Jennifer Mauldin (2006) outlined a basic process necessary to convert maps stored in AI files to ArcGIS-compatible geodatabases. She described the major steps in the process developed at the Nevada Bureau of Mines and Geology to convert their maps, but detailed information was not given. In this paper, we hope to shed more light on the conversion process and give a more detailed account of the process and its nuances.

At the Tectonics and Structural Geology Research Group at The University of Tennessee, we have a large collection of detailed geologic maps covering over 100 USGS 1:24,000-scale 7.5-minute quadrangles. We developed an efficient process to convert to geospatial databases the maps that had been prepared in a legacy digital format in order to facilitate research, analysis, and regional map compilations, and to preserve the products of over 40 years of detailed mapping mostly in the southern Appalachians. The process had to be compatible with our workflow for digitizing paper and stable-base Mylar maps, i.e., both processes need to utilize the same database schema and quality control (QC) process and produce the same end products. Over the last year, we have developed the process outlined here. Throughout the process description, software commands and interfaces are referenced in the text and may also be shown in the figures. The software referenced in this paper is Adobe Illustrator CS3 and ArcGIS 9.2 with an ArcInfo license level. While there are not significant differences between recent versions of either software package as they pertain to the process outlined here, some differences may exist. Most of the commands and interfaces should be the same or very similar for Illustrator 10 and newer, and for any ArcGIS version 9.x.

The process consists of six major steps. First, the AI file is exported to one or more CAD drawings. The CAD drawings are inspected and shapefiles of the pertinent classes from each drawing are exported and spatially adjusted in ArcMap. The referenced features are checked and then attributed using custom ArcMap tools and reference imagery exported from Illustrator. The database is checked for topology errors and edge-matched with adjoining map databases if necessary. The finished database is QC'd, and any necessary revisions are incorporated. Finally, the feature classes are symbolized, annotated, placed in a layout in ArcMap, and exported for final editing. This is an evolving process that is constantly being revised, and as such is open to comments and suggestions from the geologic mapping/GIS community.

Illustrator File Preparation and Exporting

One of the most powerful features of the Adobe Illustrator software package is the ability to store a virtually unlimited amount of vector artwork and text in layers. This permits individual features to be organized by type and the layers to be turned on and off, greatly improving map organization and editorial workflow. When converting an AI file to a GIS-compatible format, object layering in the Illustrator file becomes critical. Using AutoCAD drawing files (DWG) as an intermediary, the attributes of object outline color, line weight, and containing layer are maintained in the attribute table of the CAD feature class. This enables feature attribute querying in GIS software based on those fields and the unique values within them. Accessing the features and their attributes through a GIS, however, is dependent on properly setting up the AI file for export to CAD and the subsequent processing steps during the conversion to a vector GIS format.

The steps to prepare the AI file for export to an AutoCAD drawing (DWG) file are as follows: (1) separate the artwork into layers named by the geologic feature type (for example, inclined bedding, antiform overturned, contact certain, etc.); (2) densify and straighten linework that has been drawn with Bezier curves; (3) export the cleaned-up AI file to a DWG file and examine it for errors in content; and (4) export images (TIFF or JPEG) of the complete map, and/or any other important components, to use as a reference later in the feature attribution process. The following discussion of these steps will detail the most critical actions that lead to successful conversion. Individual results will vary based on the quality and complexity of the input artwork, so testing these steps on a small AI file that is easy to manipulate will be the best way to develop a method that is appropriate for your project.

Layering

Separating the artwork into layers in Illustrator is the first and most critical step in the conversion. At this point, think about how the artwork in the AI file will be stored as features in a geodatabase. If your organization has an existing database schema where feature types, attributes, and feature representations are already defined, the process of organizing the AI file is simplified considerably, because these parameters can be applied to a layer-naming convention in Illustrator rather easily. If this is not the case, careful planning has to be done to ensure that there is consistency (and a level of universality) in the arrangement of the artwork in layers, since the layer name becomes the most critical attribute in the DWG file. In this case, you may need to review the content of several AI files to evaluate the type and scope of features contained in your maps.

Setting up a simple geodatabase to house the results of the conversion is also recommended. It should be structured to hold a minimum set of attributes so features can be identified, symbolized, and manipulated easily and consistently. There are many resources to aid in geodatabase design, namely those available from the ESRI Support website (*http://support.esri.com*; search “geodatabase design”). Once the feature types or classifications have been established, sorting the features into layers can commence. Illustrator has the capability to select objects based on certain aspects of their appearance, such as stroke and/or fill color, stroke weight, or graphic style. Using these tools, all polygons representing the same rock unit can be selected simultaneously based on their fill color, or all lines representing concealed contacts can be identified by their stroke color and weight, then placed in the appropriate layer, for example. Figures 1, 2, and 3 are examples from a geologic map that was separated into layers in this way. In each figure, the name of the layer where the object resides (e.g., map unit “Omb” in Figure 1) becomes the content of the “Layer” attribute of that object in the exported DWG file. Other attributes from the artwork that are recorded in the attribute table of the exported DWG file are stroke color (indexed value from 1 to 255) and stroke width (in hundredths of millimeters). Unfortunately, fill colors are not recorded in the attribute table of the Polygon class in the DWG file.

Another aspect to consider during this process is feature topology. Illustrator does not maintain topological relationships of objects in the same manner as a CAD or GIS system. Points, lines, polygons, text, and other objects can be placed in layers together in Illustrator, and their graphical attributes can be mixed. A classic example of this in Illustrator is the application of a fill to a line that is not closed: it looks and behaves like a polygon, but is not truly so in terms of CAD/GIS feature topology. In CAD and GIS feature classes, topological relationships are explicitly defined and are not interchangeable within that class, i.e., objects in a CAD or GIS feature class can be of only one topological type: point, line, or polygon. Points are a single node or vertex, lines are a set of vertices connected to each other in the order in which they were drawn,

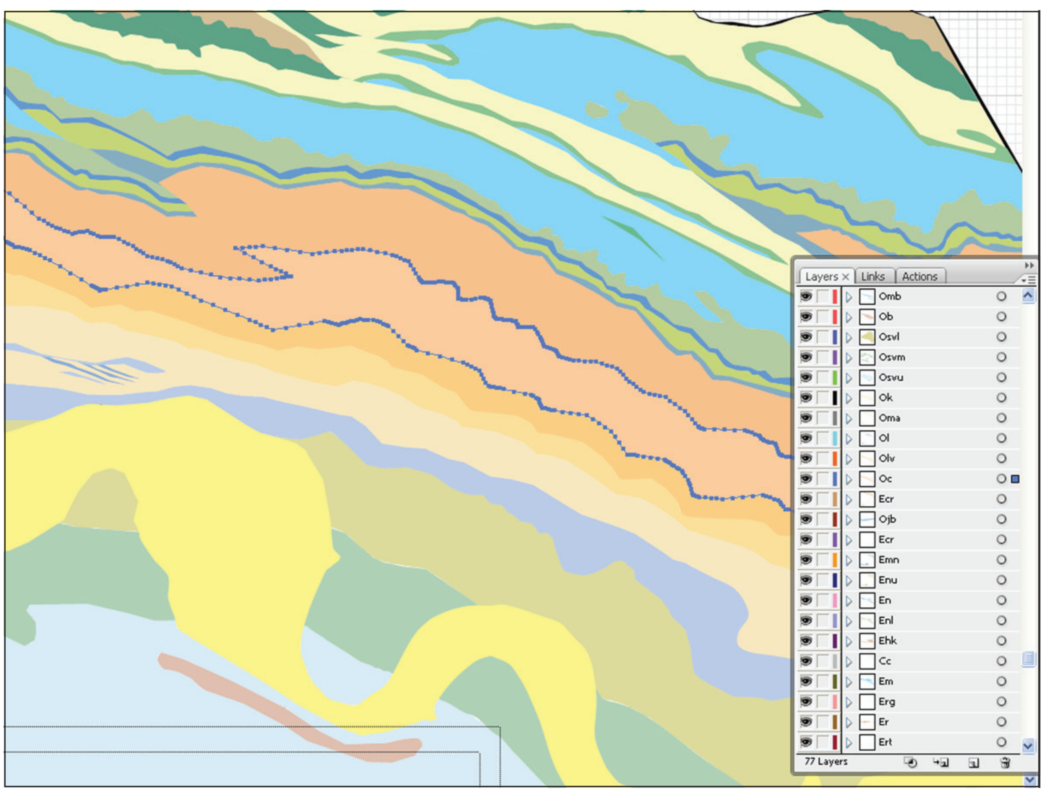


Figure 1. Rock units are separated into layers by unit code in Adobe Illustrator. The “Select > Same > Fill Color” command is very helpful in selecting all of the map areas or polygons for each rock type at one time.

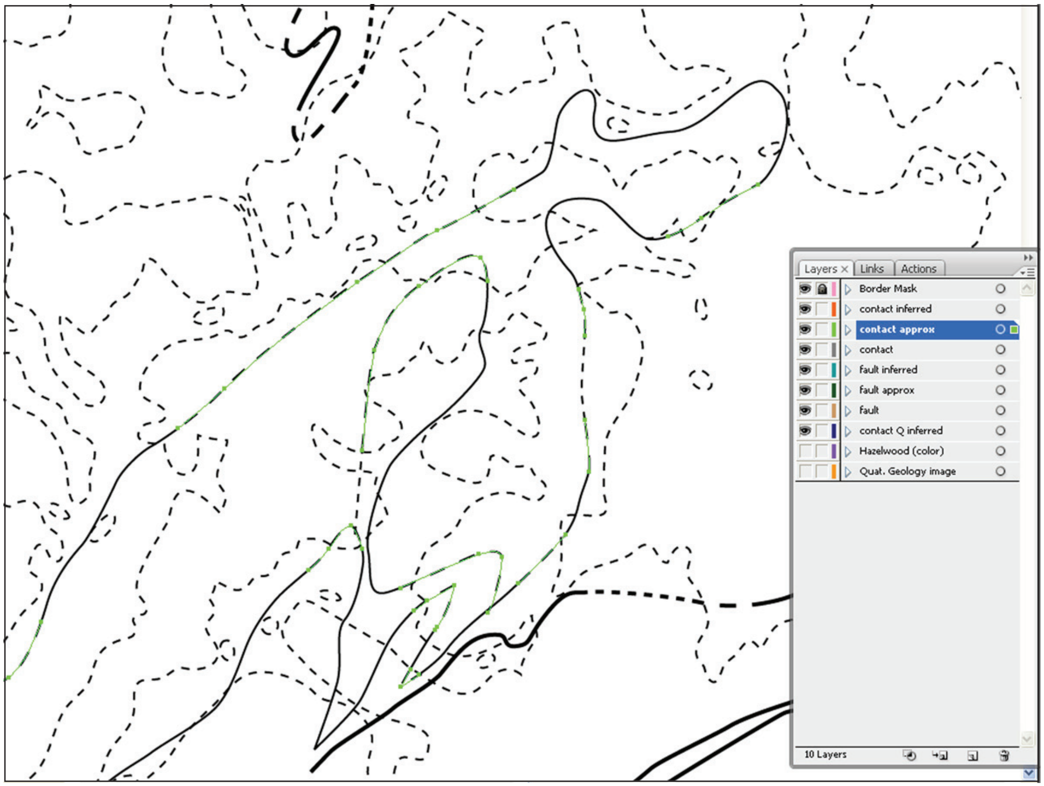


Figure 2. Faults and contacts are separated into layers by type in Adobe Illustrator. The "Select > Same > Fill & Stroke" command is very helpful in selecting lines that share the same dash and weight properties.

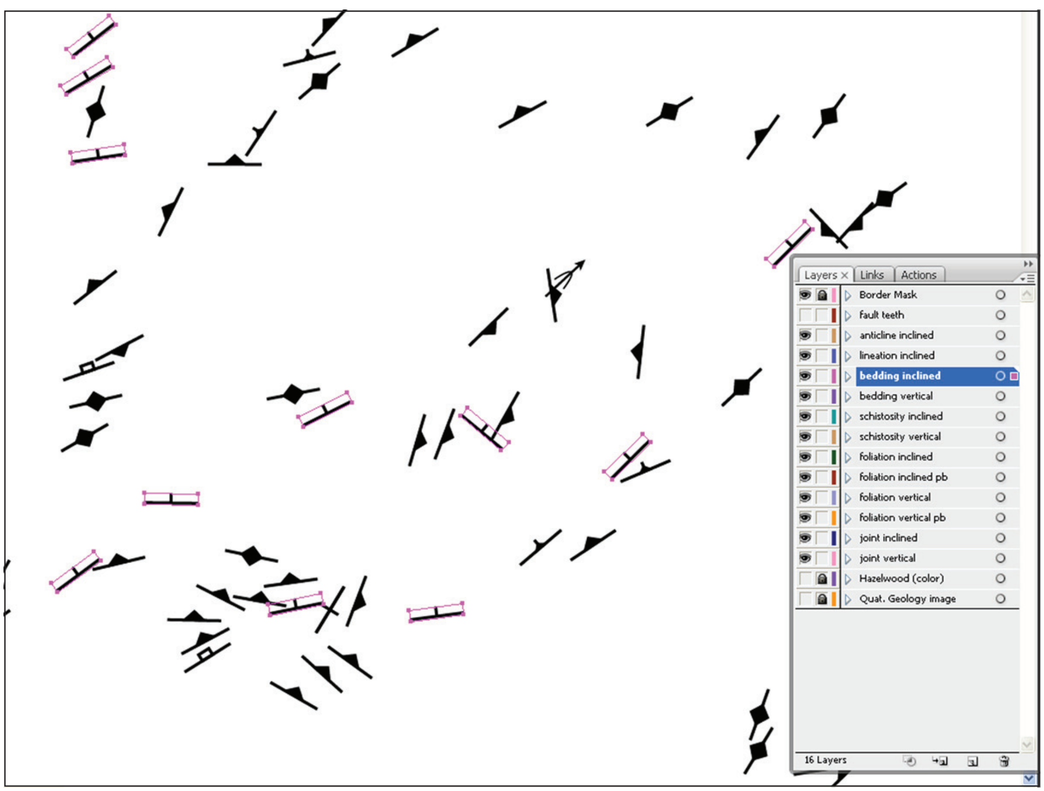


Figure 3. Symbology is separated into layers by type in Adobe Illustrator. If the symbology is built from the Symbol palette, the "Select > Same > Symbol Instance" command can be used to select each type. If the symbols are simply grouped paths, separate them into layers leaving the groups intact.

and polygons are areas completely enclosed by such a line. This is important to consider when preparing the AI file for export to a CAD drawing, since the Illustrator DWG export engine inspects each object to determine the CAD feature class to which the object will be written, regardless of the layer in which the object resides. Often, objects that look like polygons in Illustrator are just filled lines, and as such will not be written to the Polygon feature class within the DWG file as one might expect. Properly closed paths (polygons) in Illustrator will create an output to both the Line and Polygon CAD classes, because the export engine sees the object as both a path (line) and a closed shape (polygon). If the integrity of polygons is a primary concern during the conversion process, special care will need to be taken to ensure that the shapes are closed properly in Illustrator. Polygons can be recreated in ArcMap (with an ArcEditor or ArcInfo license) from topologically clean lines (lines with no dangles, no self intersections, etc.), so in some cases, such as contact lines that delineate rock unit boundaries, it might be more efficient to ignore the polygons in Illustrator and recreate and attribute them later in ArcMap. Object grouping in Illustrator is also a concern when exporting to a DWG. Grouped artwork will be exported as a composite or "multi-part" shape, which may be topologically undesirable in some cases. Structural symbols (foliations, lineations, fold axes, etc.), on the other hand, may be grouped objects that should be maintained as multi-part features until they can be processed later in ArcMap. Consequently, it is advisable to select and ungroup artwork where topology must be maintained, making sure that the ungrouped objects remain in the appropriate layers.

There are many resources on the web for Illustrator scripts that help clean up and fix artwork. The Swiss Federal Institute of Technology in Zurich (ETHZ) has developed a set of tools for Illustrator that can be helpful in some of these tasks. They are available free of charge from their website (*http://www.ika.ethz.ch/plugins/index.html*) with one caveat: the tool dialogs are written in German (although there is an English version of the documentation available, along with some helpful examples). For more information about topology in ArcGIS, see the ESRI support website (*http://support.esri.com*) and search with keyword "topology."

Preparing Artwork for Export

Once the artwork has been cleaned up and separated into layers, it can be readied for export from Illustrator to a DWG file. In this process, the artwork in the AI file is visually assessed and densified appropriately, then straightened to remove any Bezier curves. It is necessary to do this when exporting DWG files for use in ArcGIS, because ArcGIS does not natively support the viewing/importing of CAD curves, which are known as "splines"; it simply ignores objects that have an Entity value of "Spline" in the CAD attribute table. If you have access to AutoCAD or another CAD software package that can fully read/convert DWG files to shapefiles, the process of densifying and straightening the linework is not necessary in Illustrator, because most of the professional CAD software export engines will do this automatically. During development of the AI to GIS conversion process, we experimented with several other conversion options and software packages. While it is possible to export artwork as a DWG or DXF (AutoCAD drawing exchange format) with the Bezier curves preserved as splines, the subsequent export to a shapefile did not always provide satisfactory results. In some cases the attribute tables in the exported shapefiles did not contain all the original DWG attributes, and in others the density of vertices was not sufficient to maintain the smooth shapes of the original Bezier curves. For these reasons, and the fact that the conversion *can* be accomplished successfully using only Illustrator and ArcGIS, the process outlined here uses the densification and straightening method in Illustrator.

Inspect the artwork in Illustrator and get a sense for the relative density of vertices among the objects in each layer. Artwork may have very different density of vertices or drawing styles, and not all the layers or objects need to be densified to the same extent. For instance, a 7.5-minute quadrangle boundary line is probably a path composed of only four "corner" vertices and does not need to be densified, whereas rock unit contacts are drawn with smooth Bezier curves and will need to be densified several times. Once the layers that need densification are identified, the number of iterations of the "Object > Path > Add Anchor Points" command can be determined. In most cases, three to five iterations of the command is sufficient. The tool is "dumb" in that it does not inspect the distances between vertices to determine the need for an additional point. The command simply places an anchor point half way between each existing anchor. This has the effect of making some areas far too dense and others a bit sparse. This is usually not a problem; once the linework is converted to a GIS format, the lines can be generalized with a displacement tolerance that will remove the extraneous points while maintaining the integrity and smoothness of the original artwork. When in doubt, densify again to ensure that there are enough vertices in the sparse areas. If polygons were created from linework using the "Pathfinder > Divide" tool in Illustrator, densify the lines and the polygons the same number of times to ensure they maintain the same density. When each layer has been densified, all the artwork that will be exported to the DWG file should be selected and straightened using the "Object > Path > Simplify…" command. Use the "Straight Lines" option to remove all Bezier curves (Figures 4 and 5).

Export to AutoCAD DWG

After the artwork has been prepared, it can be exported to the DWG file. When a DWG file is exported from Illustrator, objects are written to the output file in the order in which they were drawn (or subsequently reordered) in the layer, from the lowest layer in the stack to the highest; i.e., the bottommost object (first to be drawn) in the bottommost layer is written

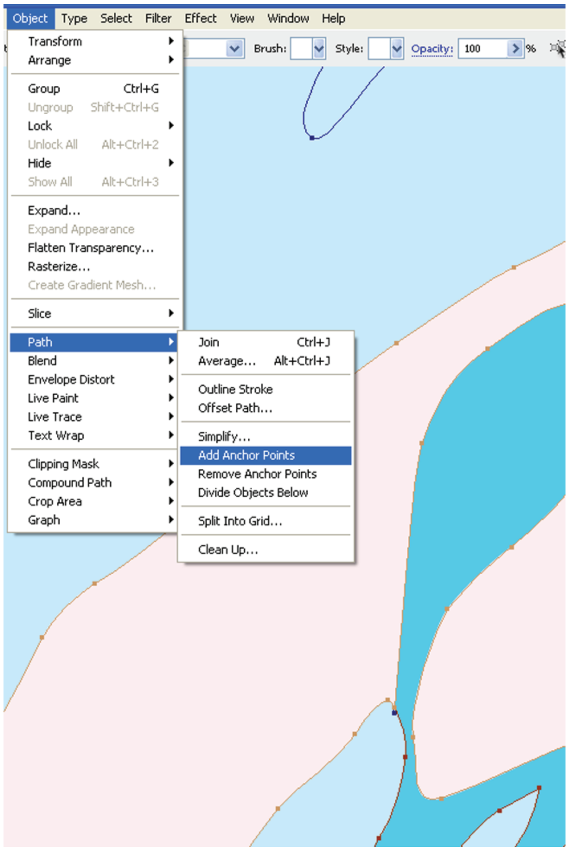


Figure 4. Use the "Object > Path > Add Anchor Points" command three to five times to densify linework that has been drawn with Bezier curves, to preserve the shapes as closely as possible.

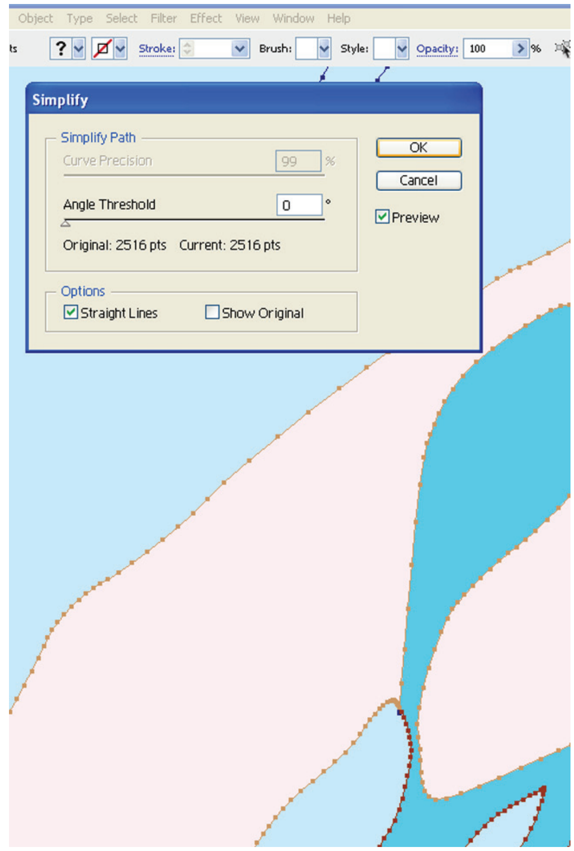


Figure 5. The "Object > Path > Simplify…" command dialog has options to smooth and generalize lines. Checking the "Straight Lines" option removes Bezier handles and readies artwork for export to an AutoCAD DWG file (without splines).

first, then the next object in the bottommost layer, and so on, layer by layer. With points and lines, the export order is of little consequence, but with polygons, this can have the effect of one polygon obscuring another when previewed in ArcCatalog or when loaded into ArcMap and viewed with the default color fill symbology. This may give the impression that there are polygons missing or that the export did not work correctly when in actuality the polygons are just obscured. The most common example of this phenomenon is a map border polygon stored in an upper layer of the map obscuring polygons, such as rock units, drawn in lower layers. As a general rule, move the border or mask layer to the bottom of the layer stack in Illustrator prior to export so that it will be drawn before the polygons of other layers when viewed in ArcCatalog or ArcMap.

Exporting to DWG is usually fast, depending on the complexity of the artwork being exported. One way to speed the export is to process only a selection of artwork. Unlock all the layers that have artwork to be exported. Use the "Select > All" command or Ctrl+A to select all the artwork in the unlocked layers. Next, navigate to the "File > Export…" command, name the output in the Export dialog box, and click "Save." In the DXF/DWG Options dialog, choose the lowest version of DWG file available (R13/LT95) and check the option to "Export Selected Art Only." The remaining default export settings can be accepted (Figure 6). In testing, the version of AutoCAD drawing did not seem to matter, but the assumption that older formats are generally simpler and thus more interchangeable was the motivation for using the oldest version available. If you want the DWG files to be used in or exported to shapefiles from AutoCAD, export from Illustrator using the file version that matches your release. To better organize the different types of features being exported from Illustrator and to help make the content checking easier, export several DWG files, one for each type or group of features. For a typical geologic map, that means exporting three files: one for map symbology, one for linework, and one for polygons.

This is also the point at which a graphic of the complete map or individual layers (station labels, symbology, and dip-strike data, etc.) can be exported as an image to be georeferenced in ArcMap and used as a guide to check the DWG file for errors or omissions, and for feature attribution. Generally, a 300 dpi TIFF image is ideal, but there may be instances where the combination of artwork size and resolution exceeds

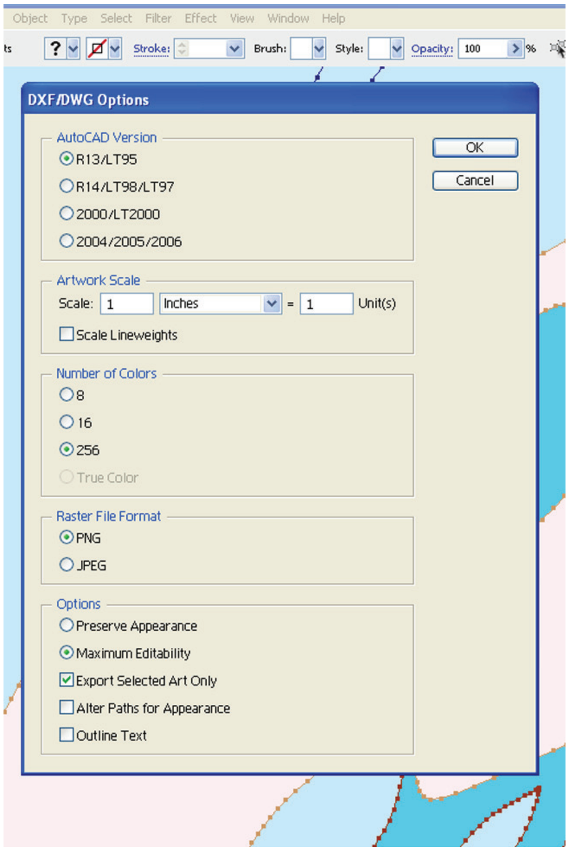


Figure 6. Adobe Illustrator DXF/DWG export options dialog. Use the lowest available file version and choose to export only the selected artwork to maximize export efficiency. All other options can remain the default values.

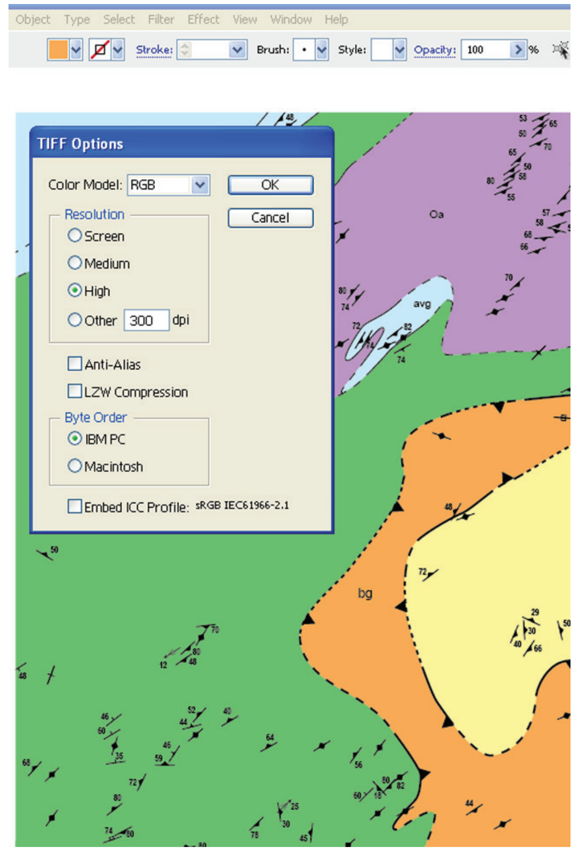


Figure 7. Adobe Illustrator TIFF export options dialog. Use RGB color mode and if necessary turn off the "Anti-Alias" option to reduce the complexity of the export while keeping the resolution high in order to maintain legibility in the image. Optionally, enable LZW compression to reduce file size.

Illustrator's capacity to write the output file. If so, ensure there are no extraneous points or text beyond the expected outer extent of the content that is to be exported, as this is the leading cause of (unexpected) failure of the TIFF export. Also, turn off any unnecessary layers. If the export continues to fail after removal of unnecessary artwork and/or turning off layers, uncheck the "Anti-Alias" option if it is not already, since this also reduces the complexity of the output. As a last resort, reduce the output dpi a small increment, e.g., 250 instead of 300 dpi, until the export succeeds (Figure 7). This completes the Illustrator portion of the conversion process.

DWG Files to Feature Classes

When the DWG export is complete, the contents of the file can be viewed in ArcCatalog (or ArcMap). Check the Polygon and Polyline classes, as appropriate, for content (Figure 8). If there are features missing, inspect them in the original Illustrator file to make sure that they were straightened. Occasionally, there will be one or more features that will not export properly. Make note of these and use the reference imagery as a guide to digitize these features into the database at some later time. When the exported DWG files have been sufficiently vetted, the process of putting the features into feature classes can begin.

DWG Conversion to Shapefile

AutoCAD DWG files cannot be edited directly in ArcGIS; in order to manipulate the features, the CAD feature classes will need to be stored in an ArcGIS-editable format. When we first developed this process, the preferred method was exporting to shapefiles, spatially adjusting the shapefiles, and appending them to a geodatabase. Since that time, more efficient methods have been established to get the classes directly into a geodatabase. But the shapefile, which for many organizations may be a staple of their geospatial data storage structure, is a good choice for storing and sharing GIS datasets because it is a format that is widely accepted and read/written by many CAD and GIS software packages. For these reasons, the process to convert and spatially adjust the CAD feature classes as shapefiles will be outlined here.

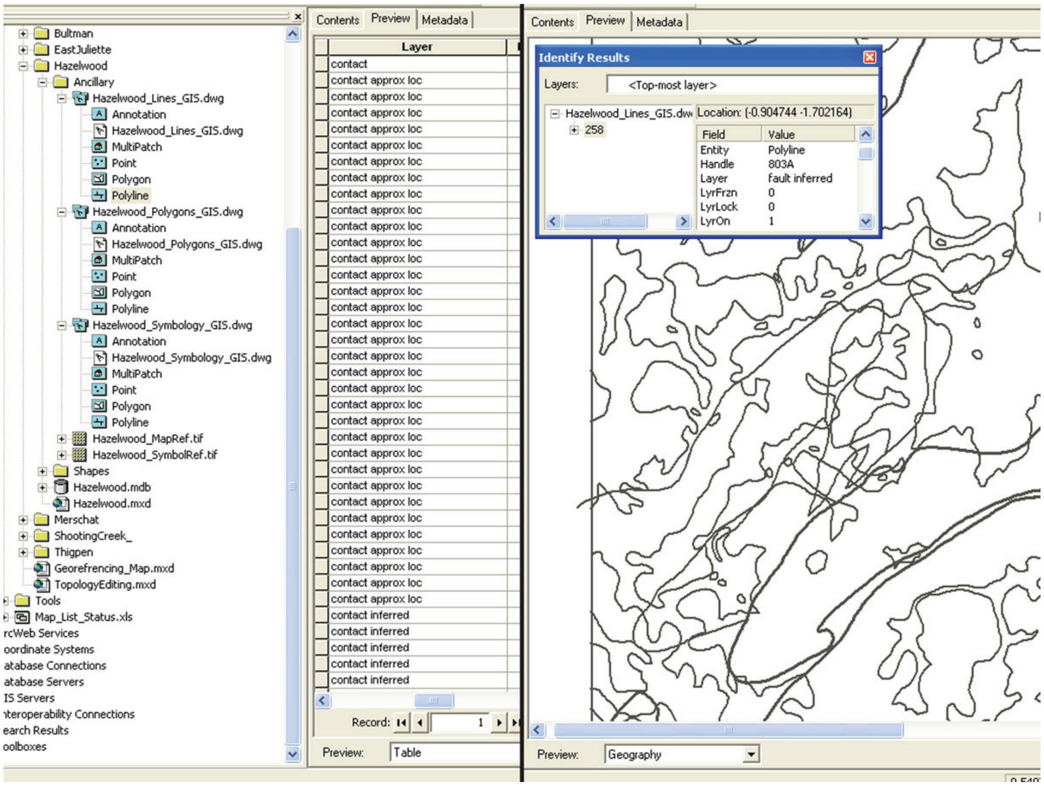


Figure 8. ArcCatalog is used to inspect the contents of the DWG file. Check the Polygon and Polyline classes of each DWG file for content by selecting the class and previewing the attribute table. The Identify tool can also be used to check the properties of individual features.

There are two common ways to export CAD feature classes to shapefiles: one uses ArcMap and the other ArcCatalog. The options and dialogs for these two methods are quite different. In ArcMap, export options, aside from the output location and file name, are virtually non-existent, so this method is not recommend. ArcCatalog utilizes the "Feature Class to Feature Class" ArcToolbox script, which is more advanced and has more robust options for the output. Of particular importance are the Field Map and SQL query, which allow the user to export selected fields and selected features, respectively. To initiate the export to shapefile in ArcCatalog, simply right-click the appropriate CAD feature class and choose "Export > To Shapefile (single)…" (Figure 9). Once the dialog appears, set the output location and file name for the shapefile. A SQL query can be created in the "Expression" field to export only a selection of features. The bottom pane of the dialog window is the Field Map, where the user can select the attribute table fields and their names in the output. This is the great advantage of using the Feature Class to Feature Class tool in ArcCatalog to export the shapefiles. Unnecessary fields in the CAD feature class can be dropped from the output, and fields that are to be kept can be renamed and re-dimensioned to match existing schemas (e.g., "Layer" [*type* String, *length* 255] can be renamed to "Label" [*type* String, *length* 50]). Generally, the only field that is kept is the "Layer" field, which is renamed and dimensioned as in the previous example.

Before viewing and editing the exported shapefiles in ArcMap, check them for structural problems by running the "Repair Geometry" ArcToolbox script. The script can be accessed through the ArcToolbox "Data Management Tools > Features" toolset. The purpose of running this tool is to repair invalid feature representations in the shapefile structure that may exist after export from CAD. The most common problems fixed by the script are null or empty geometry, self-intersections, and improperly sorted rings in polygons ("donut" polygons with inner and outer rings drawn in opposite directions). Errors of this type are usually not visible and do not affect map display. These errors usually manifest themselves when you attempt to edit or perform geoprocessing functions on the shapefiles. Fixing these errors helps ensure proper behavior of the features, whether in the shapefile or in a geodatabase. Also, execute the "Simplify Line" or "Simplify Polygon" tool (whichever is appropriate) located in the "Data Management Tools > Generalization" toolset. These scripts help clean up the shapefiles by removing small "hiccups" in the features and extraneous points that were added during the densification process in Illustrator. The dialogs for both scripts are basically the same, with the option to set a maximum allowable offset for points in the output. The polygon version adds the option to set a minimum area for the simplified shapes. Generally, a small offset around 0.1 m (0.3 ft) is enough to allow removal of most of the extra points while maintaining the shapes. Some errors in feature topology that are introduced in the process are fixed by the tool itself, while others can be fixed later using ArcGIS Topology tools. If simplifying a line class and a polygon class that have

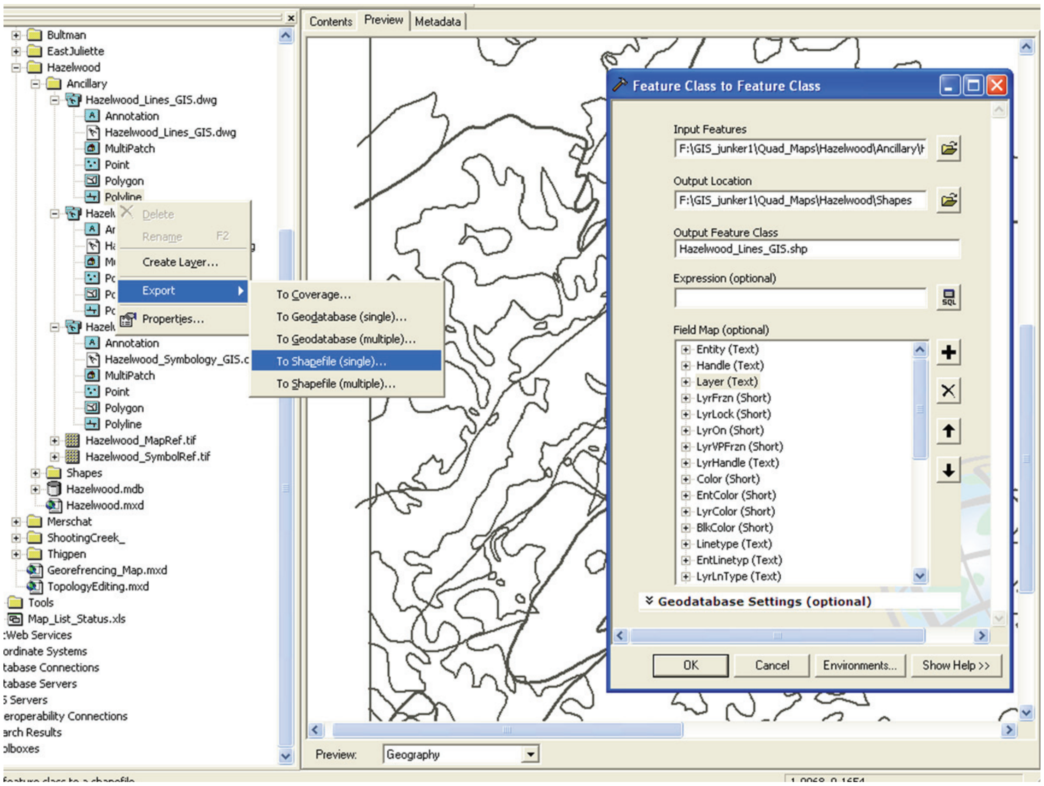


Figure 9. ArcCatalog is used to export the appropriate class from each DWG file to a shapefile via the "Feature Class to Feature Class" tool. This dialog allows the user to set the output location and file name, as well as specify a SQL query and remap and/or re-dimension the fields from the input DWG attribute table to the output shapefile attribute table.

shared geometry (i.e., the polygons were created from lines using the "Pathfinder > Divide" tool in Illustrator), be sure to simplify both classes using the same tolerance. This will help reduce the number of errors later when validating the feature topology.

Spatial Adjustment and Appending Features to Geodatabase

Once the shapefiles have been exported they can be loaded into ArcMap and spatially adjusted. If you are familiar with how to georeference imagery in ArcMap, the process of spatial adjustment is very similar. By adding control points that link the coordinates in the shapefiles (which maintain the CAD file coordinate system) to a properly projected grid or "footprint" from another feature class that matches the extent of the original map, the contents of the shapefile "snap" to the new, projected coordinates. Once the features have been snapped, the projection of the shapefile can be defined in ArcCatalog. It is important to remember that spatial adjustment only adjusts the coordinate space and updates the extent of the features; it *does not* set the projection. USGS 7.5-minute quadrangle map-based features are the easiest to spatially adjust, as the USGS quadrangle index grid can be obtained in shapefile format free of charge from a number of web sources (e.g., GeoCommunity- *http://data.geocomm.com/quadindex*). Most of the maps that we have converted have been partially or fully quadrangle-based, so most of the spatial adjustments are as easy as linking the four corners of the quadrangle feature in the shapefile to the appropriately projected quadrangle polygon (Figure 10). For more information on the spatial adjustment tools, see the ArcGIS Desktop Help.

With the shapefiles properly spatially referenced in ArcMap and their projections defined in ArcCatalog, the features can be loaded into the appropriate classes in the geodatabase, or used as is. We prefer to load the adjusted shapefiles into a geodatabase to take advantage of the organizational and editorial advantages of the geodatabase, such as the Topology tools. Use the Append tool located in the "Data Management Tools > General" toolset to append features to the appropriate classes in a geodatabase. Generally, there should be at least four feature classes in a geologic feature geodatabase: (1) a line or polygon class that defines the map extent ("footprint"); (2) a polygon class to store rock units; (3) a line class to store faults and contacts; and (4) a point class to store stations with structural and lithologic information. Additional classes can be added to store surficial deposit polygons, cross-section lines, annotation, and other cartographic or geologic features. The Append tool has a dialog similar to that of the Feature Class to Feature Class tool, and has the ability to map the fields from the input to the output when you select the "NO_TEST" Schema Type option (Figure 11).

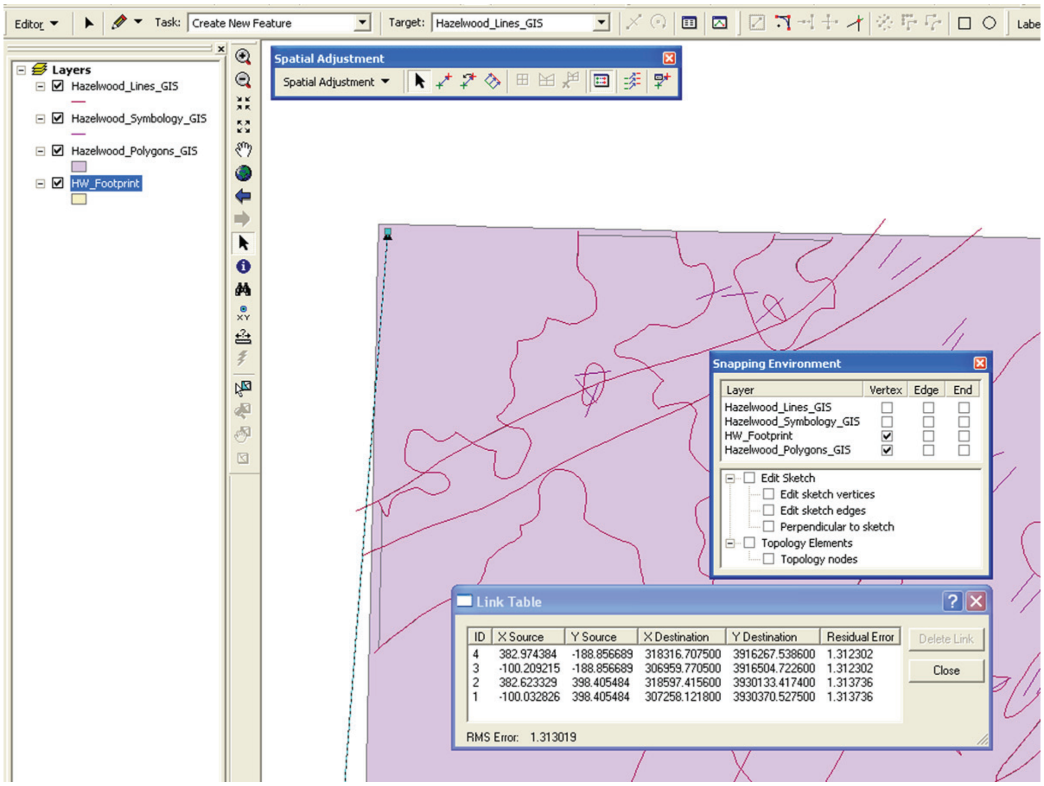


Figure 10. Exported shapefiles are loaded into ArcMap and spatially adjusted by snapping the corners of the "footprint" feature in the shapefile to the corners of a projected quadrangle boundary feature already stored in the geodatabase. Note the small root mean square (RMS) error in meters. If the error is more than a few meters, verify that the footprint shape is correct.

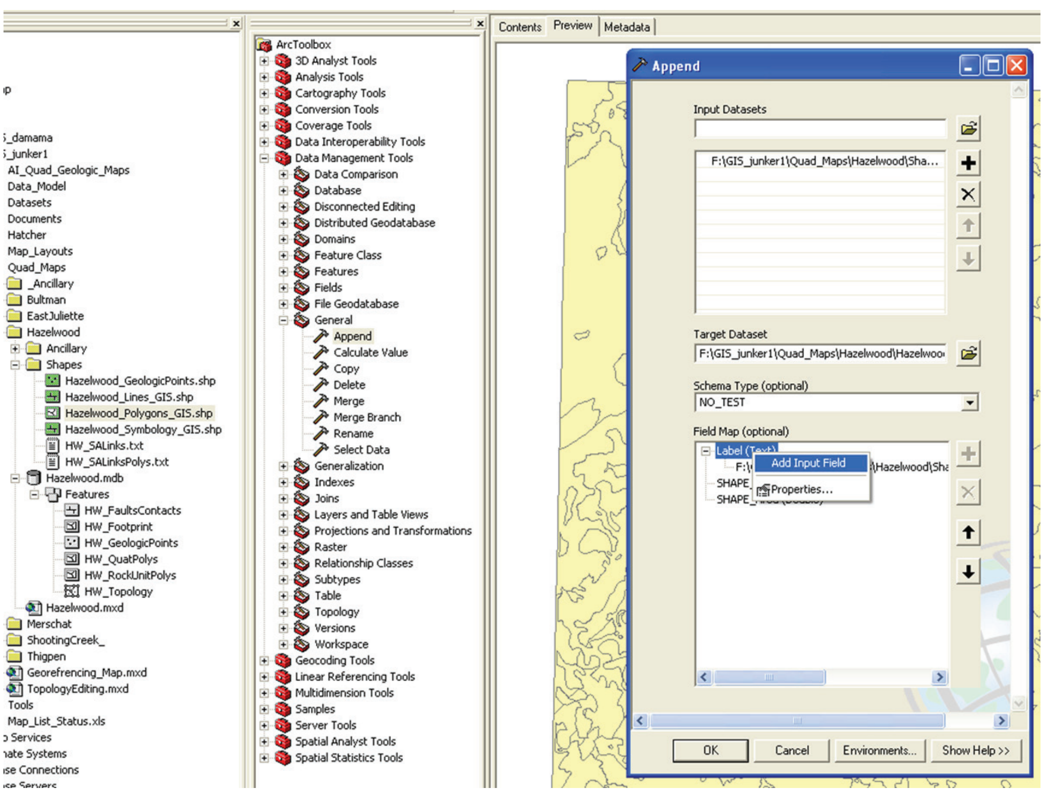


Figure 11. The Append tool can be used to add the features from the spatially adjusted shapefiles to the appropriate class in the geodatabase. Use the "NO_TEST" schema option to map fields from the shapefile attribute table to the geodatabase feature class attribute table.

Geologic Symbology Processing

If one of the adjusted shapefiles contains features that represent geologic structural symbology, it will need additional processing to convert it to point features in a geodatabase feature class or shapefile, with appropriate attribution. This step in the conversion process is the least certain in terms of the specific tasks needed to get to a finished product. Depending on the nature of the symbology that was used in Illustrator, the conversion can take a number of different paths. Ideally, the original map in Illustrator has a layer that contains the station locations, labeled with the station ID, as well as a stand-alone table (e.g., an Excel spreadsheet or a tabular text file) that has the rest of the station information based on that same ID. These station "points", which probably exist as small polygons (circles or squares) in the symbology shapefile, can easily be converted to point features and then manually attributed with their station ID from a background reference image in ArcMap. The station point feature class' attribute table can then be joined on the station ID to the table containing the additional station data. With the tables joined, the attributes from the stand-alone table can be referenced to define the symbol type, color, text label, etc., for the ArcMap layer, to be used in the finished map. This is, of course, the ideal situation. For many older paper or Mylar maps that have been redrafted in Illustrator, it is usually not possible, because the station data exist only in a field book and the stations were marked on a paper or Mylar map. If this is the case, some additional scanning, georeferencing, and digitizing in ArcMap, and transcription of field book data may be necessary to bring the station features up to par with their newer, digitally captured counterparts.

Most of the AI files that were created by our group use a relatively consistent symbol set that was propagated in a template file from map to map as each old paper map was redrafted, or as new maps were drawn in Illustrator. The symbols were constructed of simple lines and polygons, and with some clever querying and attribution in ArcMap, the meaningful parts of the symbol could be isolated and converted to points with a couple of basic attributes. First, start an edit session in ArcMap and select all the features in the symbology class and "explode" the multi-part features so that each part of the symbol can be selected individually. If the features are in a shapefile, the "Length" field will have to be added to the table manually and the values calculated using the Field Calculator or Calculate Geometry command in the table view. The basic process of flagging features to retain entails sorting through the features and identifying ways to isolate and attribute different parts of the symbology (Figures 12 through 17). In this example, the "Length" attribute is used to help separate the symbol parts (Figure 12), and an attribute called "Keep" is created to flag the selections in the table. After calculating the "Keep" attribute (Figure 13), systematically pan around the map searching for problems, correcting the "Keep" attribute as necessary. Once all the features have been inspected, features with "Keep" = 1 are selected and an ArcMap Field Calculator expression is used to determine the azimuthal rotation (strike) of the feature (Figure 14). The "keeper" features are now ready to be converted to points and appended to the geodatabase (Figure 15). Note that some of the points may need adjustment in order to be located accurately. A custom tool for ArcMap called "Attribute Features" that was developed with Visual Basic for Applications is used to assign the Dip (or Station) value to each feature using the reference imagery that was exported from Illustrator as a guide (Figure 16).

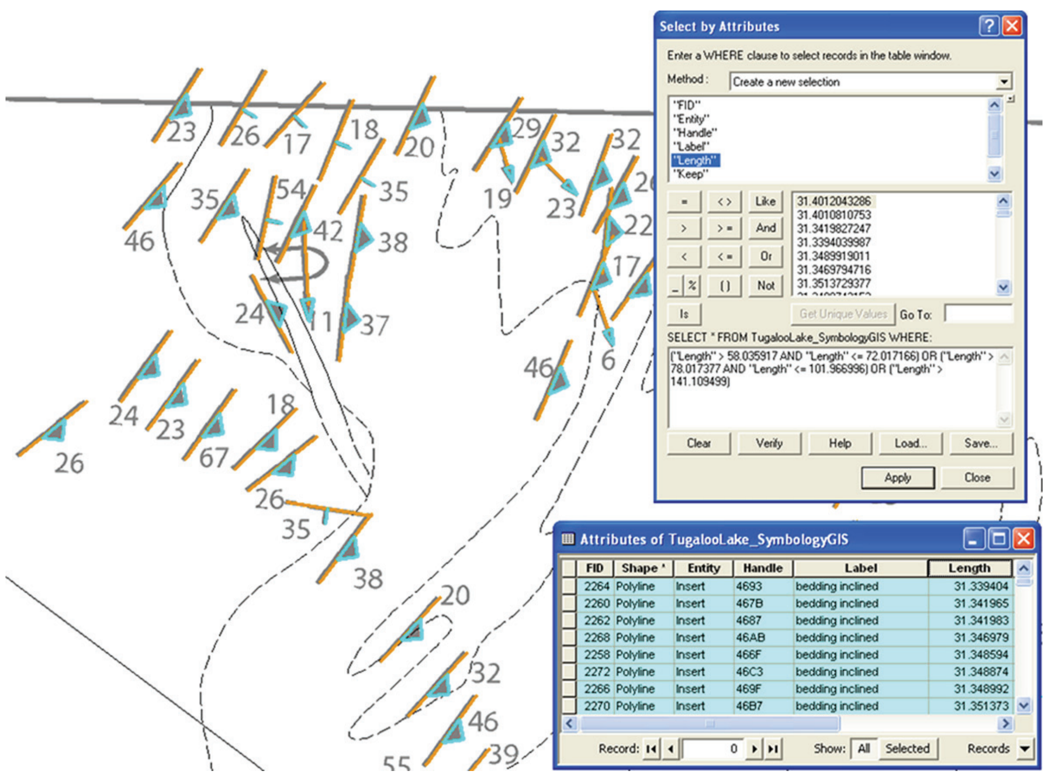


Figure 12. The lengths of the different parts of the symbology features are assessed and a query is developed to select the unwanted parts. Systematically pan around the map to make sure that the query is selecting the appropriate features before continuing.

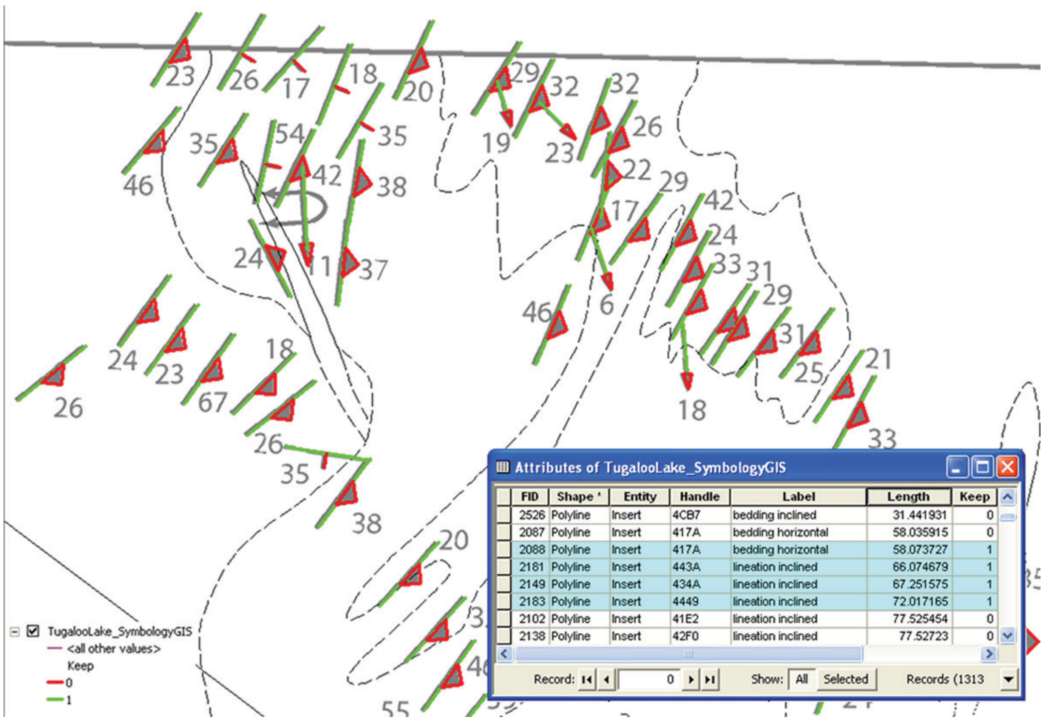


Figure 13. The selection made in the previous step is inverted and the "Keep" attribute is calculated to "1."

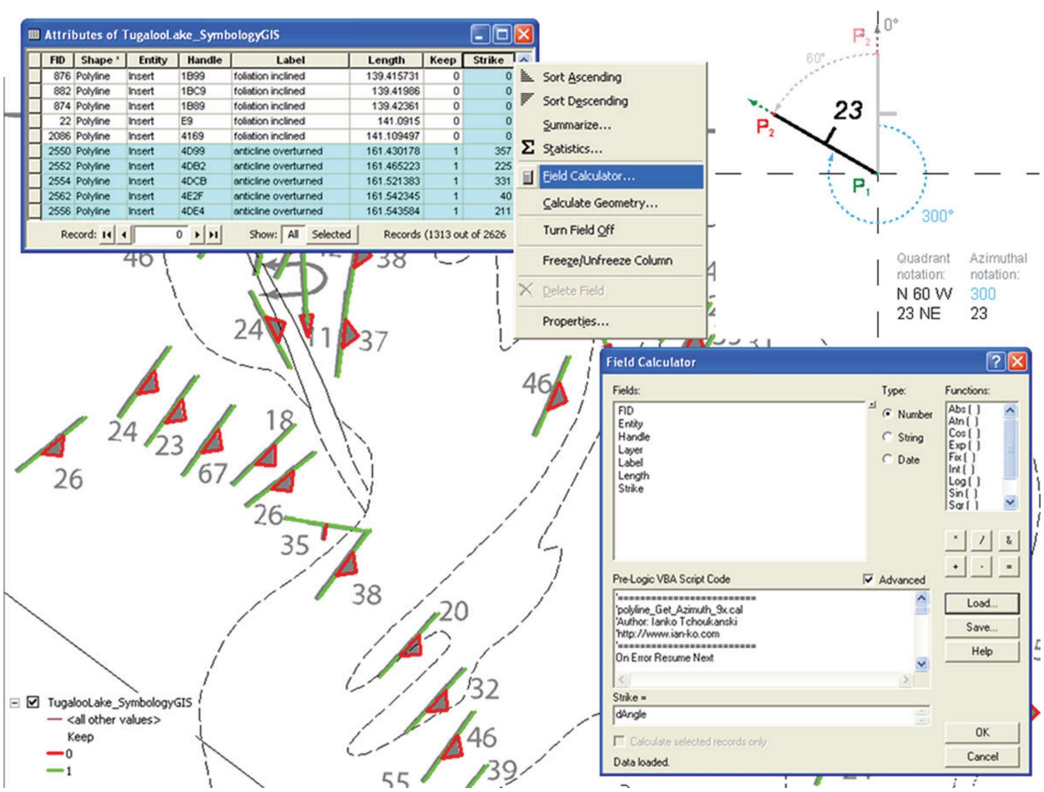


Figure 14. Features with a "Keep" attribute equal to "1" are selected and the azimuthal rotation (strike) of the feature is calculated using a custom Field Calculator expression.

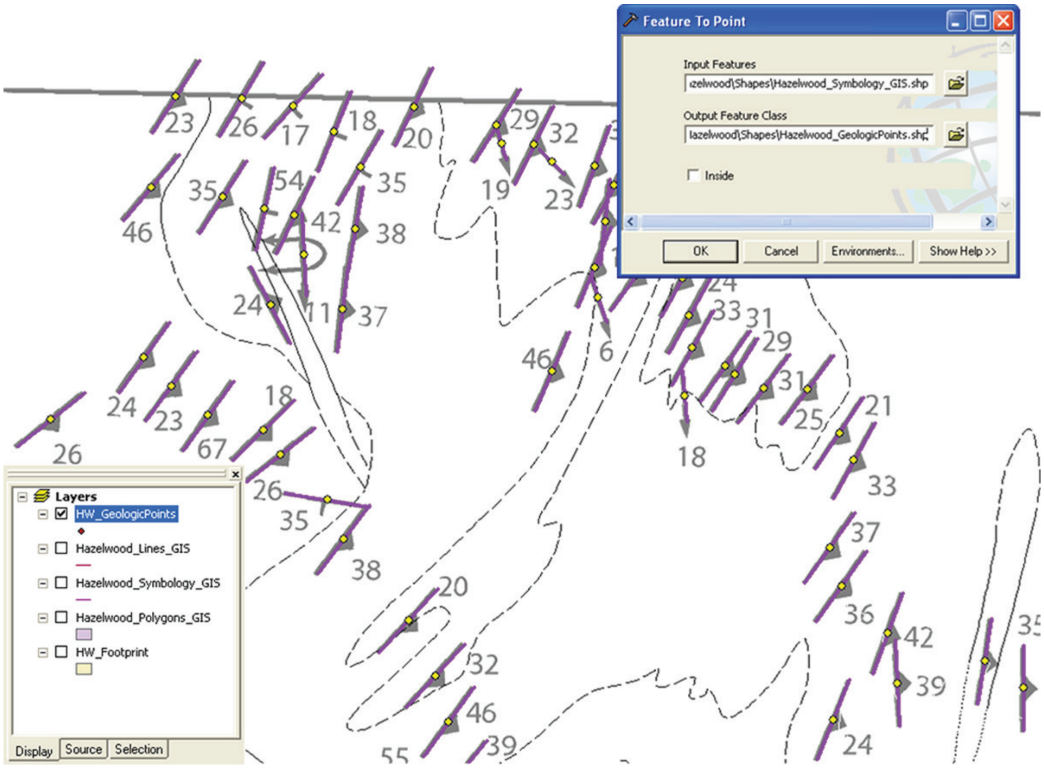


Figure 15. The “keeper” features are now ready to be converted to points using the “Feature To Point” tool. The points can be appended to the geodatabase and their locations edited if necessary.

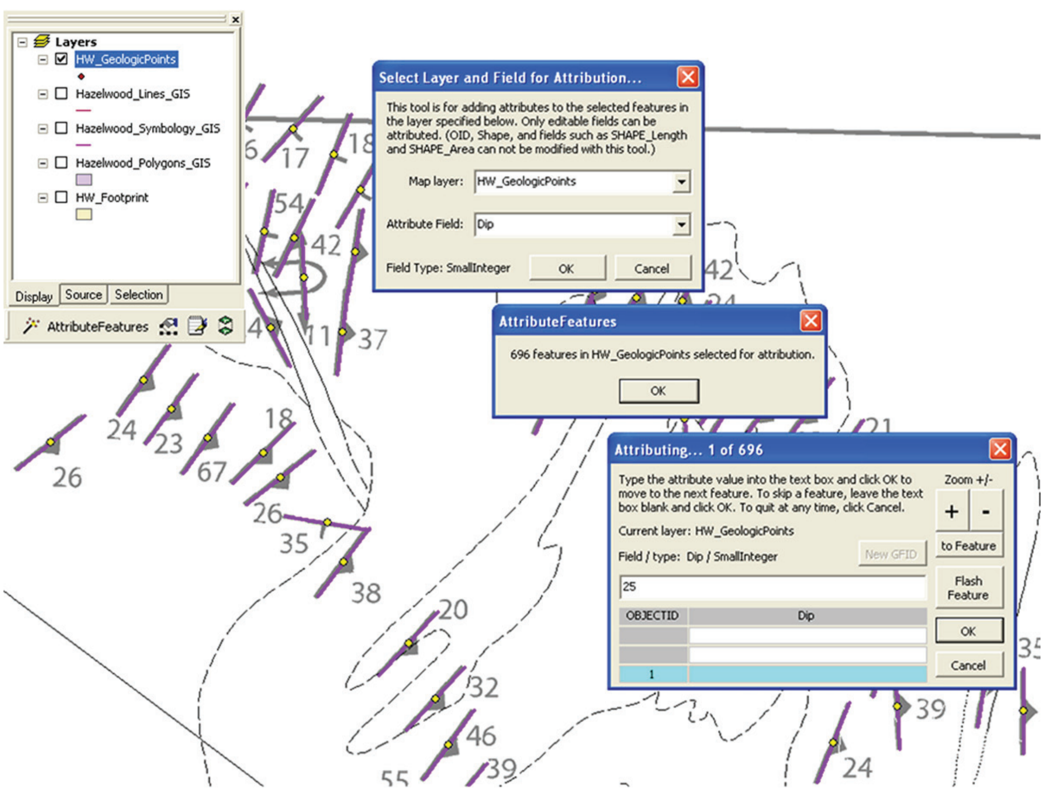


Figure 16. Attributes are added to each feature in turn using the custom “Attribute Features” tool based on the reference imagery that was exported from Illustrator.

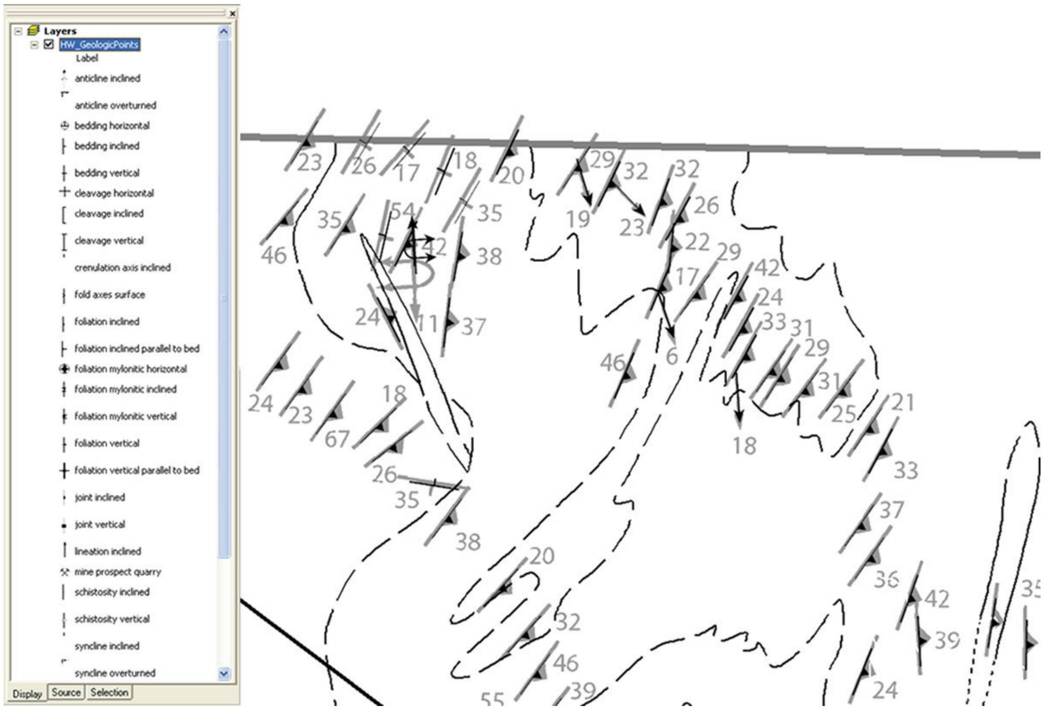


Figure 17. Symbology is applied to the points by importing an ArcMap Layer file. Errors are easily spotted and corrected. (The slight offset of the new symbology is due to incorrect offsets in the layer file, which can be easily corrected.)

Symbology is applied to the points by importing an ArcMap Layer file (e.g., GeologicPoints.lyr) through the Symbology tab in the layer Properties dialog. Finally, systematically pan around the map again looking for features that have the wrong symbol, inverted rotation, etc., and make corrections (Figure 17).

Topology, Edge Matching, Quality Control, and Final Steps

Once all of the features have been loaded into classes in the geodatabase, some of the tools available exclusively to the geodatabase can be utilized to improve the integrity and quality of the data. The following sections will briefly cover some of the most important data integrity and QC measures that can be implemented within the geologic geodatabase, as well as general quality controls that are necessary to assure that the converted maps are as good as possible.

Topology and Edge Matching

Within the geodatabase, features in different classes can be related to one another by their geometric relationships using a special type of relationship class called a Topology class. In previous versions of ArcInfo, the coverage data model had topology rules built in to help maintain feature structure validity, tolerances, and the relationships between different geometries. Shapefiles, on the other hand, do not utilize internal feature topology, because they store only one geometry type per dataset (e.g., point, line, polygon). This is one major advantage of the geodatabase; within a feature dataset, topological relationships can be defined and customized to help maintain the integrity of individual features within a feature class, as well as maintain geometric relationships between features in different classes. For more information on how topology works within the geodatabase and how to set up a topology class and define its properties, see the ArcGIS Desktop Help and search with the keywords "Topology in ArcGIS."

For geologic features, there is a simple set of topology rules that can be implemented to help correct errors that may exist in the converted CAD features, as well as maintain the geometric relationships necessary to ease editing and creation of new features at some later time. In general, the two classes that need to participate in the geodatabase topology are the rock unit polygon and the fault and contact line classes. The rock unit polygons need to be discrete and have their edges covered by a fault or contact. The faults and contacts must also be discrete, and they should not overlap or intersect each other or themselves. Table 1 and Table 2 list a basic set of topology rules for the polygon and line classes, respectively, that are necessary to maintain these essential geometric relationships. Once the rules are established, the topology can be validated.

Table 1. List of basic topology rules for polygons representing rock units.

Feature Class	Rule	Feature Class
RockUnitPolys	Must Not Overlap	n/a
RockUnitPolys	Must Not Have Gaps	n/a
RockUnitPolys	Boundary Must Be Covered By	FaultsContacts

Table 2. List of basic topology rules for lines representing faults and contacts.

Feature Class	Rule	Feature Class
FaultsContacts	Must Not Overlap	n/a
FaultsContacts	Must Not Intersect	n/a
FaultsContacts	Must Not Have Dangles	n/a
FaultsContacts	Must Not Self-Overlap	n/a
FaultsContacts	Must Not Self-Intersect	n/a
FaultsContacts	Must Be Single Part	n/a

Make a copy of the database *before* validating a topology class, because the validation process makes edits to the features and thus will occasionally produce undesired results that are *not* reversible. Once validated, the topology errors can be assessed and corrected in an ArcMap edit session, or marked as exceptions.

If the maps being converted from AI to geodatabase cover adjoining quadrangles, edge matching must be done to ensure that the rock units and contacts line up properly and have consistent attribution. Add the adjoining rock unit polygon and fault and contact line classes to ArcMap and inspect the shared edge. In an edit session, the Snapping environment can be set up so that the vertices of features from one quadrangle can be snapped to the vertices of the features in the other (Figure 18). Once the adjoining maps have been edge matched and the topology checks and edits are completed, the geodatabase spatial QC is complete.

Other Quality Controls and Final Steps

With the conversion complete, and the geodatabase spatially QC'd, any additional QC or final cleanup can be done to finish the process. Generally, there will be some additional work to make sure that all the data have been converted properly, as well as some preparation of the data to be displayed cartographically. Some other QC steps to consider are: (1) cleaning up any <null> or erroneous values in the feature class attribute tables; (2) checking the original source maps and field books or spreadsheets to verify station attributes; (3) cleaning up the workspace, including deleting ancillary or temporary files and compacting the geodatabase in ArcCatalog; and (4) preparing metadata documents for the geodatabase.

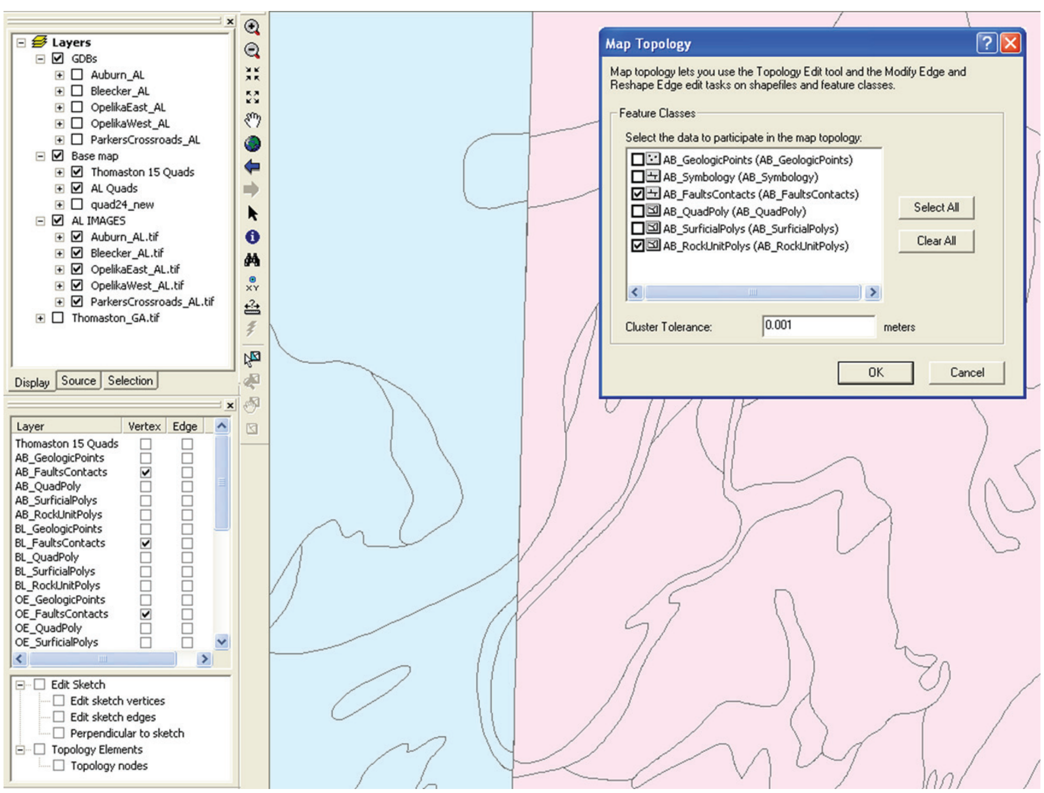


Figure 18. Adjoining maps should have their edges matched. In an edit session, use the Snapping environment (bottom left) to set the features that will take precedence over others and use Map Topology to specify classes with shared geometry.

For data that are to be displayed on a printed or electronic map, additional feature classes may need to be added to store cartographic features, such as cross-section lines and lines for holding labels or continuous graphical elements like fault teeth. Labels can be converted to annotation and their locations edited and stored permanently in the geodatabase. All the geodatabase feature classes can be added as layers in ArcMap and placed in a layout with appropriate symbology, annotations, a legend, and rock unit descriptions. ArcMap layer files can be applied to layers to keep fills, lines, and points symbolized and labeled consistently and to exact specifications. A topographic base, shaded relief image, photographs, etc. can be added to the layout to enhance the map (Figure 19). Finally, the map can be exported to any number of different graphics formats to be printed or viewed electronically, such as an Adobe PDF document or a TIFF or JPEG image.

Conclusion

This paper presents a set of steps and processes for converting maps stored in the popular Adobe Illustrator digital graphics format to GIS-compatible shapefiles and geodatabases. This is a working method, and, as such, suggestions for improvements are encouraged and welcomed. In addition to the presentation from the DMT'08 meeting (available online at *http://ngmdb.usgs.gov/Info/dmt/DMT08presentations.html*) and this paper, a thread covering the topic of AI file conversion can be found on ESRI's Mapping Center blog at *http://blogs.esri.com/Support/blogs/mappingcenter/* (search for "DMT"). Any questions or suggestions regarding the process should be directed to Andrew Wunderlich (*gibbon@utk.edu*) or posted to the ESRI Mapping Center blog.

References Cited

Hatcher, R.D., Jr., 2005, Non-survey, non-digital completed geologic maps in file drawers and theses: How can they be transformed into useful available digital geo-spatial data?, *in* Soller, D.R., ed., Digital Mapping Techniques '05—Workshop Proceedings: U.S. Geological Survey Open-File Report 2005–1428, p. 11-21, *http://pubs.usgs.gov/of/2005/1428/hatcher/*.

Mauldin, Jennifer, 2006, Converting Adobe Illustrator maps to ArcMap format, *in* Soller, D.R., ed., Digital Mapping Techniques '06—Workshop Proceedings: U.S. Geological Survey Open-File Report 2007–1285, p. 165-168, *http://pubs.usgs.gov/of/2007/1285/pdf/Mauldin.pdf*.

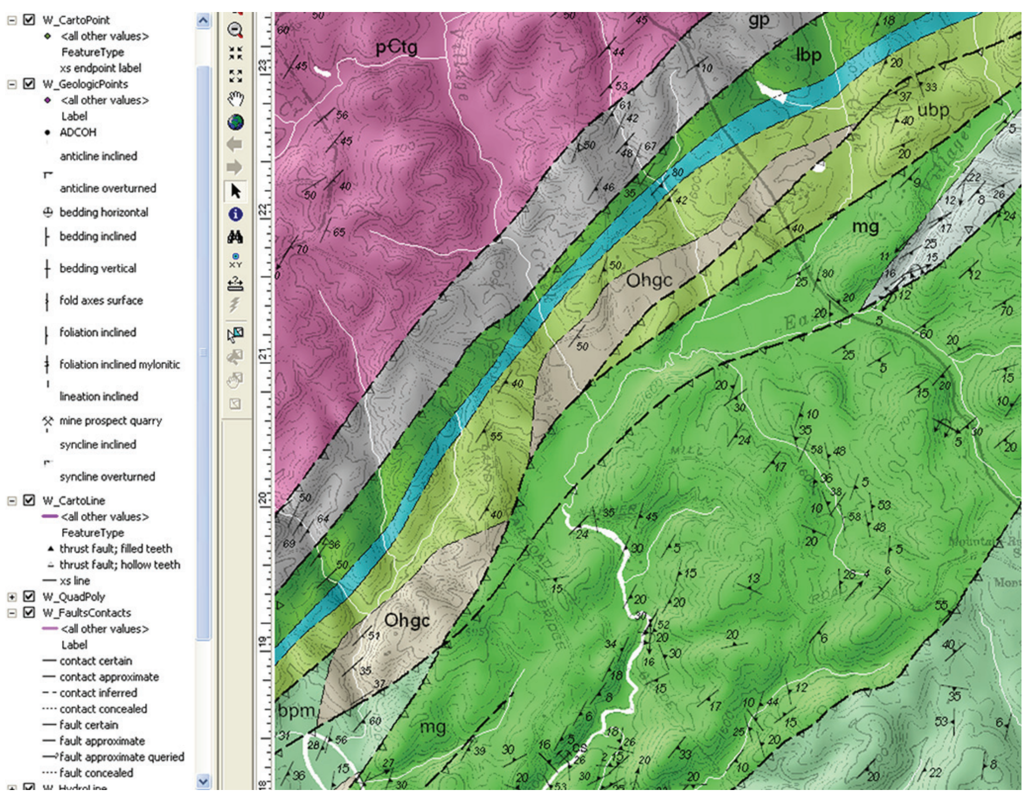


Figure 19. Sample geologic map with proper symbology and a hillshade image, in ArcMap.

Vocabularies for Geoscience Information Interchange

By Stephen M. Richard[1] and David R. Soller[2]

[1]Arizona Geological Survey / U.S. Geological Survey
416 W. Congress # 100
Tucson, AZ 85701
Telephone: (520) 770-3500
Fax: (520) 770-3305
email: *steve.richard@azgs.az.gov*

[2] U.S. Geological Survey
926-A National Center
Reston, VA 20192
email: *drsoller@usgs.gov*

Introduction

Development of a digitally networked global community has progressed from simple text based interchange to progressively richer content, including audio, video, maps and imagery of all sorts. Metadata and semantic content descriptions are necessary for more effective search, discovery, and evaluation of these various types of information. In addition, the sheer volume of accessible content begs for more automation in the acquisition and analysis of data; the key to such automation is interoperability.

Information interoperability is built on a 'stack' of shared protocols and interchange formats (Figure 1). The hardware and network parts of this stack constitute the infrastructure of the Internet. There is a tremendous amount of ongoing work to develop file formats and schema to achieve the intermediate or schematic levels of interoperability—e.g., well-defined file formats (netCDF, SDTS, shapefile, XML…) and markup languages that implement particular domain-specific information schema. For example, GeoSciML (*http://www.geosciml.org/*) is a markup language developed for geoscience information interchange. Within this schema, there are various elements (like database fields) that are populated using geologic and other terminology lists. Semantic interoperability occupies the top of the information interchange stack and involves understanding the meaning of content transported via the underlying stack elements. Semantic interoperability requires agreement between data providers and data consumers on shared concepts and the mechanisms to represent concepts.

Interoperability is predicated on the idea that the data consumer and provider do not have to negotiate the format and content model for each information interchange individually. The engineering concept is to construct patterns or protocols (service definitions) for discovering, acquiring, and utilizing content that do not require the consumer to have any knowledge of how the provider is implemented. Semantic interoperability in such an architecture requires mediation between concept representations used by the provider and consumer if they do not use the same system; the simplest example of such mediation is language translation. Software tools for semantic mediation are still in their infancy, so the best way to know what someone else means is to use a shared vocabulary of controlled terms.

A controlled vocabulary is a collection of concepts. Each concept in the vocabulary has a definition and one or more assigned terms (e.g., names) that are, effectively, labels for the concept as used in everyday or scientific communication. Each of these terms has a scope—the community of users who use that term or label for the concept in the vocabulary. Typically terms are scoped by association with a language; for example, Spanish or French, or, if the word "language" is used in a more general but less familiar sense, "geoscience language." Within any particular scope there should be a one-to-one mapping between terms and concepts. A controlled vocabulary may also include relationships between concepts (especially hierarchical relationships) (Richard and others, 2003). The identity of a controlled concept is based on its definition, not on the term used to label the concept.

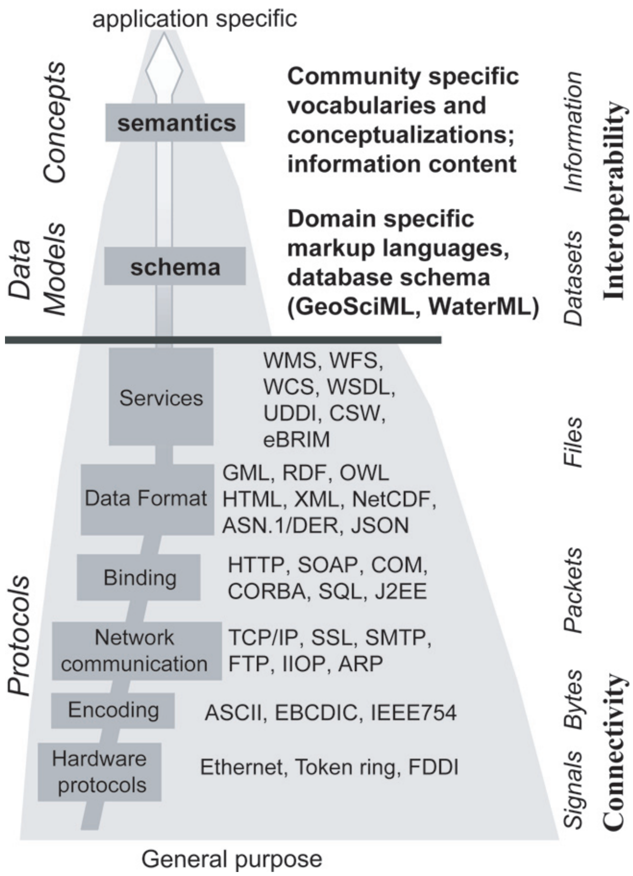


Figure 1. Interoperability stack. This diagram represents the collection of protocols and specifications that enable interoperability. General purpose, low-level specifications in the lower part of the diagram enable basic network connectivity, starting at the hardware level, working upward to services that specify collections of operations and basic transport protocols. These 'system' protocols are built on top of one another, with each layer dependent on the underlying layers and adding progressively more complex functionality, from basic signal interpretation ('0' or '1') to delivering digital files. Many of these protocols are so widely adopted and used that most users are not aware of them. The solid line in the upper part of the diagram separates these system protocols from more application specific data models that start to define domain-specific file content and structure; these have narrower applicability, but are necessary for computer-based automated content packaging and interpretation. At the top of the stack is the ultimate objective of interoperable system design—the conveyance of information between systems with only minimal human intervention.

A conceptual data model for the topic or domain of interest dictates the kinds of controlled vocabularies required. For example, the NADM-C1 (NADMSC, 2004) model includes 'WeatheringCharacter' as a property of a geologic unit. Because this property is specified by a term rather than descriptive, free text, a controlled vocabulary of terms that specify different weathering character values is necessary. The North American Data Model's (NADM-C1; *http://nadm-geo.org/*) use of a controlled term list was chosen to facilitate interoperability. Controlled vocabularies make possible the clear and unambiguous communication of content.

Vocabularies for Shared Use

The USGS National Geologic Map Database Project (NGMDB) has been supporting community development of standardized vocabularies for several years, mostly through participation in the NADM's Science Language Technical Team (NADM-SLTT, 2004; *http://pubs.usgs.gov/of/2004/1451/nadm/*), the GeoSciML Concept Definitions Task Group (*https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG*), and at the project level (e.g. Richard and others, 2003). From this work, numerous vocabularies (approximately 42) either were defined or adopted for use by the NGMDB project. Most of these were compiled informally for project use and have not been published.

The development of these NGMDB vocabularies was coordinated with the project's efforts to (1) implement a federated (USGS – State geological survey) database from the NADM conceptual model; (2) design a data-entry tool for populating this database with geologic map information according to these standard vocabularies; and (3) convey a simplified view of the Nation's geology via a subset of the federated database and an interface, the NGDMB Data Portal. The Data Portal is described in Soller (this volume). For the purposes of the Data Portal, five of the compiled vocabularies were used – lithology, genesis, particle sorting, weathering character, and proportion (e.g. proportion of a geologic unit that is composed of a specified rock type). These five vocabularies are briefly described below. The NGMDB Data Portal vocabularies, and those developed in anticipation of a NGMDB federated database, are available online at *http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/*; previous versions of each standard vocabulary also are archived there.

Lithology

Science language technical teams formed under the auspices of the North American Data Model Steering Committee (*http://nadm-geo.org/sltt/*) developed vocabularies for sedimentary and metamorphic rocks, and adopted existing standards (Streckeisen, 1976) for use with igneous rocks (NADM-SLTT, 2004; *http://pubs.usgs.gov/of/2004/1451/nadm*). Our synthesis of these vocabularies into a single lithologic classification produced a vocabulary with 2027 terms. Over the past several years, project experience developing a user interface to utilize this vocabulary, and testing it with geologic users, demonstrated that this list is too large and the relations among terms too complex to be successfully utilized without considerable training.

Based on this experience, we determined that a smaller vocabulary would be necessary for integrating geologic maps displayed through the NGMDB Data Portal. The lithology category vocabulary for the portal will be used for searching and for online map services to report the composition of map units. Because the map services are to be accessible to a wide audience, we required that the terminology should be broadly understandable. Simultaneously, demonstration vocabularies for use with GeoSciML interchange documents were developed by the Concept Definitions Task Group of the Interoperability Working group of the CGI (CDTG). The senior author led development of both the NGMDB and CDTG vocabularies; they are identical except for some minor differences discussed below.

The CDTG vocabulary was assembled by a group of geologists from various countries, who discussed the kinds of lithology categories they thought should be included in a simple lithology vocabulary consisting of about 100 terms. As for the NGMDB Data Portal, the purpose of this vocabulary is data integration, not detailed scientific categorization of the full spectrum of materials found in the Earth. The initial list of terms was reduced and balanced in an attempt to include equivalent depth of detail for various families of rocks (igneous, sedimentary, metamorphic). Generalized category names had to be added in some cases where there is not a commonly used lithology term in order to allow construction of a hierarchy of categories (e.g., composite genesis material, fault-related material). The resulting vocabulary contains 146 terms, and is available at *https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG*.

The NGMDB Data Portal lithology vocabulary has some minor differences with what has emerged as the CDTG (version 200811) vocabulary. These differences are discussed here. The NGMDB vocabulary does not include *Foidite* and *Foidolite*. These rocks, which consist of greater than 60 percent feldspathoid mineral, are distinguished in the CDTG 200811 vocabulary by grain size (phaneritic versus fine-grained), following LeMaitre and others (2002). For NGMDB purposes, these unusual rocks are not differentiated based on grain size, and so they are aggregated into one category, *Feldspathoid rich igneous rock*, to denote any igneous rock with more that 60 percent modal feldspathoid. The CDTG 200811 lithology vocabulary includes *phyllonite*; NGMDB does not include this because it is an unusual rock type that is sufficiently represented by the *Mylonitic rock* or *Phyllite* category. Several categories not included in the CDTG lithology vocabulary are included in the NGMDB lithology vocabulary. A generic *Compound material* category represents any sort of rock or unconsolidated material that is part of the Earth. NGMDB lithology also includes *Rock formed in surficial environment*, *Weathered rock*, and *Residual Material* categories to allow composition description of units that are mapped/defined based on presence of these sorts of materials. CDTG 200811 did not include such categories based on the argument that protolith or precursor terms should be used. This produces a potential incompatibility in that composition specified by one of these categories would have to map to CDTG 200811 *Unconsolidated material*, which may not be a very accurate mapping.

We have tested the NGMDB lithology vocabulary by using it to categorize lithology for State geologic maps of Arizona, Idaho, Oregon, and Washington, as well as the Geologic Map of North America. Our conclusion is that the vocabulary has worked well for this map synthesis, and we plan to continue using it. Variations with the CDTG vocabulary with the CGI Interoperability working group are being discussed and hopefully will resolve discrepancies between the vocabularies.

Genesis of Earth Materials

The purpose of this vocabulary is to define categories that may be used to specify the geologic origin, setting, and processes by which geologic units or materials were formed. The implementation of these aspects or properties of genesis is somewhat different in the GeoSciML v.2 model and the NGMDB Data Portal schema. The NGMDB portal follows the GeoSciML v1.1.1 scheme by associating a genetic category property (GrossGenesisTerm in GeoSciML v1.1.1) with a geologic unit. In GeoSciML v.2 the genesis of a geologic unit is disaggregated into a collection of one or more events, each with process and environment properties. The genetic categories in the NGMDB Portal vocabulary can be parsed into implied process or environment properties to map into the GeoSciML v.2 schema.

Particle Sorting, Weathering Character

Vocabularies for characterizing the particle sorting and weathering character of geologic units were included in the NGMDB data-entry tool software and were tested during the process of parsing into the Data Portal the geologic map descriptions on selected national and State geologic maps. Not unexpectedly, particle sorting and weathering character were seldom found to be generalizable for regional map units and so were not used in the Data Portal. They are provided here because we anticipate they will be more useful for detailed map descriptions in local areas. Regarding comparable vocabularies in GeoSciML, the NGMDB vocabularies were compiled before the CDTG work had advanced, so these term lists were submitted as contributions for the CDTG members to consider. When the CDTG completes its work, we anticipate adopting their vocabularies for future use.

Proportion

This vocabulary provides terms that may be used to qualitatively express the abundance of a rock type in a geologic unit. It is a simple list including Dominant, Present, Subordinate, Minor, and Rare.

Summary

An international community of geoscientists is working to develop shared vocabularies for information interchange. The advantage of using shared vocabularies is that a participating agency only has to do one mapping—to and from their agency's vocabulary to the standard, shared vocabulary. The downside is that information may be lost when specific agency terms must be mapped into generalized or non-equivalent terms in the shared vocabulary. This is offset by the substantial benefit for users, because they aren't required to interpret and understand the different terminologies in use by each data source. The NGDMB project has long supported this international effort and provides numerous science vocabularies at the website *http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/*. These vocabularies are relatively stable in their content, but some of them are still evolving. Therefore, they are here provided informally, and have not been fully critiqued and edited in order to meet USGS and other agency standards for editorial consistency. However, we anticipate they might be found useful by individual agencies and by the international standards-development community, as a resource and possibly for incorporation of the terms and definitions.

References

Le Maitre, R.W., ed., Streckeisen, A., Zanettin, B., Le Bas, M.J., Bonin, B., Bateman, P., Bellieni, G., Dudek, A., Efremova, S., Keller, J., Lameyre, J., Sabine, P.A., Schmid, R., Sorensen, H., and Woolley, A.R., 2002, Igneous rocks: A classification and glossary of terms: Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks: Cambridge, Cambridge University Press, 236 p.

NADMSC (North American Data Model Steering Committee), 2004, NADM conceptual model 1.0, A conceptual model for geologic map information: U.S. Geological Survey Open-File Report 2004-1334, 60 p., *http://pubs.usgs.gov/of/2004/1334*.

NADM-SLTT, 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, *http://pubs.usgs.gov/of/2004/1451/nadm/*. [Includes all vocabularies as appendices to this report.]

Richard, S.M., Matti, Jonathan, and Soller, D.R., 2003, Geoscience terminology development for the National Geologic Map Database, *in* Soller, D.R., ed., Digital Mapping Techniques '03 — Workshop Proceedings: U.S. Geological Survey Open-File Report 03–471, p. 157-168, *http://pubs.usgs.gov/of/2003/of03-471/richard1/*.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.

A Classification of Geologic Materials for Web Display of National and Regional-Scale Mapping

By David R. Soller

U.S. Geological Survey
926-A National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6977
email: *drsoller@usgs.gov*

The Geologic Mapping Act of 1992 mandates the U.S. Geological Survey (USGS) and Association of American State Geologists (AASG) to design and build a National Geologic Map Database (NGMDB), as an archive of map-based, standardized geoscience information. The science and technical standards for this archive have been under development since that time, and mostly consist of revisions and modifications to standards that have evolved in the geosciences since the 1800s. Numerous reports of progress have been included in previous Proceedings of the Digital Mapping Techniques workshops and elsewhere (see, for example, Soller and Stamm, this volume).

The NGMDB project delivers geoscience information in several ways including via a Geoscience Catalog which provides, for each of ~80,000 publications, one or more web links to the publishing agency and in many cases to downloadable data and images (*http://ngmdb.usgs.gov/ngmdb/ngm_catalog.ora.html*). In a recent initiative made feasible after the development of certain science and technical standards, the project began to design a Web-mapping portal (the NGMDB "Data Portal," *http://maps.ngmdb.us/dataviewer/*, see Soller, 2008) where the full richness and variability of map information content is managed by the publishing agencies or other repositories, with a subset of the information made available in a standardized and coherent fashion via this Portal, for browsing and querying and, in the future and on a limited basis, for downloading.

In this paper I address, but do not presume to solve, a particularly challenging task—that is, how to effectively portray many geologic maps together, in a coherent fashion, via a Web-mapping system. Geologic maps vary significantly in content owing to factors including the purpose (e.g., mineral exploration, economic development, groundwater modeling), map scale, geologic terrane, and the geologic concepts in use when the map was made. Even if we examine the most recent intermediate- to detailed-scale maps for a region, the differences among them commonly are sufficient to limit the effectiveness of standard rock classifications for bringing the maps together into a synoptic view. Fault doesn't lie with the classifications but with their application to a situation for which they were not designed—that is, interactive, dynamic Web display of multiple and disparate geologic maps.

Because the geologic classification described in this paper was developed specifically for application in a Web-mapping system, and because those systems are relatively new and unevolved, it may be somewhat unconventional. Suggestions for improvement to this classification and how it is applied on the Web are welcome; I do not suppose the classification to be ideal, but it is clear that more effective methods for cartographic display of geologic information in Web-mapping systems are needed.

From my limited personal experience, I find the process of developing a classification to be difficult, fraught with ambiguities and second-guessing. It gives me newfound respect for those who have done it successfully. This paper describes how the classification was developed, in order to place it in context and to lend some small measure of insight into the process.

Design Assumptions and Principles for the NGMDB Data Portal

The design of the NGMDB Data Portal and its geologic classification is the outcome of numerous observations, assumptions, and principles regarding how people use the Web, and the type of geoscience information that is contained in geologic maps. Some are discussed below.

Complement, Don't Compete—A "Website Nonproliferation Agreement"

People who visit geoscience websites, whether professional geologists or the general public, want to quickly find the information they need; as emphasized in their emailed comments, they clearly do not want to grope amongst many similar websites, unsure which site is "best" and has the most authoritative content. This user preference is in opposition to a strongly positive aspect of the Web – that is, the unrestricted ability to "publish" information by posting it to a website. And so a natural tension exists between users and website providers. This tension can be healthy when it motivates those legally responsible for information to develop better Web-based methods of communicating it, but it obviously becomes counterproductive when the user is faced with multiple websites offering what appears at first glance to be the same content.

In designing the NGMDB Data Portal, we specifically try to complement rather than compete with, or duplicate, the Web services and information provided by the Nation's geological surveys. For example, the Portal shows a national view of bedrock and surficial geology and, with increasing levels of zoom into a given region, provides a generalized view of the geology and links to the State geological surveys where more detailed geologic mapping is available. The function of the NGMDB is, then, not a "better" dissemination of a State geological survey's published maps, but an integration of geology across the Nation, as both an educational tool and a means to find the original, detailed information.

Is Web "Publishing" Really Different from Paper? Yes and No

The intended audience for a product guides the method that is selected to convey it. For example, is it a formal, printed publication intended for professional geologists? Or perhaps is it for non-geologists who guide public decision-making? Is it a website that contains an electronic copy of a conventionally designed geologic map, and/or a geologic map database intended for downloading? Or, is it a Web-mapping system that contains formally published and/or unofficial information postings (e.g., geologic map information that has not received agency approval), designed to be interactively queried and viewed in order to address a variety of questions posed by the tax-paying general public? Web-mapping systems increasingly are a means by which the public obtains geologic map information. Although in some respects it is a fundamentally different product than a traditional map, in at least one important respect it is the same – high-quality, effective cartography remains essential.

Geologic maps convey complex and somewhat unfamiliar concepts and imprecise information, and the presentation must be done with careful thought and art, especially on the Web. This is partly because users tend to spend less time studying and learning information presented in a Web browser than they do for the printed page or map sheet. Also, because the Web interface is small in size when compared to a conventionally designed printed or electronic map sheet, methods of portrayal must be especially informative and compelling; the user will not long endure the process of clicking on a map unit, reading the information in a popup window or a mouse-over display, committing that information to memory, and then moving to another map unit and repeating the process. More complex and informative queries of the map database, specified interactively by the user, are quite challenging and expensive to design, and are not commonly found in Web-mapping systems implemented for geologic maps. Therefore, comprehension of geologic map information is still best achieved by viewing and querying the entire map in the user's local environment, hence the continued demand for downloadable GIS data and map images. For the NGMDB, and perhaps for other sites and other agencies as well, the most effective role for Web presentation of geologic maps, at least in the near-term, is to provide a quick overview with simple queries that either satisfies the user's general curiosity or encourages the user to download or purchase the printed map(s).

Good Cartography Remains Essential

"…the [geologic] maps are designed not so much for the specialist as for the people, who justly look to the official geologist for a classification, nomenclature, and system of convention so simple and expressive as to render his work immediately [understandable]…" (USGS Director, John W. Powell, 1888). These words are as relevant today as when they were written. Information on a geologic map must be readily comprehensible, and clearly presented.

For a Web-mapping system (and, in general, for any geologic map) it is critically important to portray the various rock units in a manner that highlights their similarities and differences; this is the art of cartography. By using similar colors and patterns for geologically related map units, the geologic features and relationships deemed by the author to be most significant are made more visible, thereby aiding map comprehension. Conversely, if the colors of adjacent map units are too similar, or are randomly assigned by the system, important details of geologic materials, structure, and history may not be readily discernible. The changing set of conditions under which the map, or group of source maps, is displayed in the user's browser presents a real challenge to Web-mapping system design. For example, user-specified changes in the area viewed (pan or zoom) cause a different set of geologic map units to be visible on-screen. How will those specific units be symbolized to optimally convey the geology? Will the map legend dynamically change to show just those units or will it be a static legend that shows all units in the map database?

Source versus Derived Information

Geologic mapping begins with fieldwork that includes the description of rocks and sediments (which generally are few in number and confined to points of observation). These field observations and interpretations then are mentally assembled into a conceptual 3D model that permits the extrapolation of observation points to the entire map area, thereby producing the geologic map. In general, geologic maps show an organization of rocks and sediments into stratigraphic packages or units. In many cases these stratigraphically defined units are directly usable (e.g., to predict the occurrence of oil-bearing units outside the areas where oil has been mapped). However, not uncommonly the public wants to know the nature of the material at a particular location, rather than how the geologist organized the materials into map units. For this reason, maps of lithology, geologic age, and other factors are derived from the geologic map. These derivatives are common in Web-mapping systems and can be created by a database query and dynamic display of the results or can be created by the system at any time and later displayed as static objects.

Commonly, the derivative information is created by someone other than the map author. Typically, relevant information is identified in the Description of Map Units (DMU) and, if available, in the accompanying pamphlet or report. This information is used directly to prepare the derivative map or is parsed into free-text or controlled-term database fields in order to make the information available to others. Despite the utility, and at times it seems the imperative, of deconstructing and parsing geologic map unit descriptions into various database fields, the process causes some information loss. This is true whether or not standard terminologies are used. Because the parsed information is an interpretation, derived in turn from the interpretations that are provided in the DMU, it is not equivalent in content to the direct field observations from which the geologic map and DMU were created (Figure 1). If the parsed information is derived from a pre-existing map database, it is even further removed from the actual observations. These realities guided decisions on the Data Portal's design, regarding what information would be parsed from the source maps and stored in the Portal's database, and what would be displayed in the Web browser.

A database can store multiple descriptions or science terms for any given characteristic of a map unit, derived from the DMU or the source map's database. For example, numerous lithologies can occur within a mapped unit, and each of these can be recorded in the database with an indication of the lithology's proportion. The NGMDB Portal's database uses this approach, storing information for each lithology in each map unit. However, such information is difficult to portray in a single map view, and so it is common to identify and show a single characteristic such as the dominant lithology. A derivative map such as this can be extremely useful where map units are relatively homogenous in composition; but in many areas this is the exception, not the rule. A somewhat randomly selected map of the U.S. Midcontinent includes a unit well known for its homogeneity (St. Peter Sandstone), and a notably heterogenous, cyclothemic unit (Tradewater Formation); their map unit descriptions are shown in Figure 2. How would a dominant lithology be identified for the Tradewater Formation? For this Portal, in which many maps are to be integrated into a coherent view, it was decided to minimize the "distance" between field observations and Web display by classifying and displaying information that more closely characterizes the nature of the entire map unit as defined by the original authors.

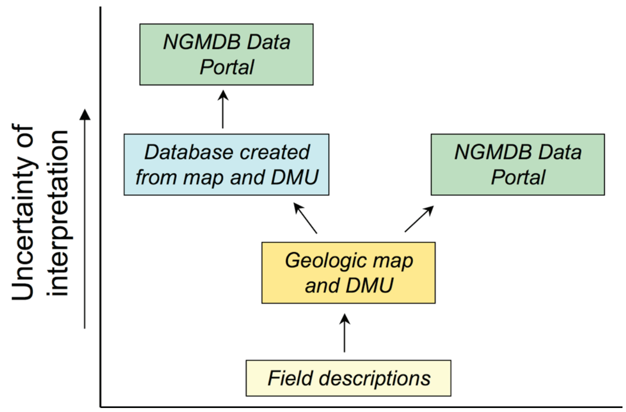


Figure 1. Diagram showing accumulation of uncertainty in the interpretation of geologic information. The most certain information is directly recorded in field observations, and on the resulting geologic maps. Uncertainty in parsing geologic map unit descriptions into database fields, whether free-text or controlled-term, increases at each process step removed from the source map. For purposes of the diagram, nuances such as the structure and content of a database directly associated with the source map are not addressed.

IPt **Tradewater Formation (Pennsylvanian; upper Morrowan through lower Desmoinesian)**—Sandstone, siltstone, shale, lenticular coal, and limestone. The Tradewater has less obvious cyclicity than younger Pennsylvanian rocks, and marker beds are more difficult to trace. Sandstones are generally sublitharenites. Thickens to the southeast; 300 to 700 ft thick

Osp **St. Peter Sandstone (Ordovician; Mohawkian)**—The sandstone is composed of nearly 100 percent white to clear quartz grains that are frosted and well-rounded. Thickness varies in irregular fashion from 50 to 210 ft

Figure 2. Comparison of lithologic descriptions for two units found in the Paducah 1° x 2° quadrangle, Illinois, Indiana, Kentucky, and Missouri (Nelson, 1998). The St. Peter Sandstone (Ordovician) is the product of repeated reworking of older sediments, whereas the Tradewater Formation is a typical product of cyclic sedimentation common in the Midcontinent region during the Pennsylvanian.

Classifications can be Comprehensive, or Selective

For the past decade, the NGMDB project and many colleagues in the U.S. and international community (for example, see Appendix A in Soller and Stamm, this volume) have steadily worked to define science and technical standards that build upon the works of many predecessors (for example, Powell, 1888). These standards address cartography, map database design, and science terminology (e.g., a list of terms and definitions for lithology). Particularly noteworthy here is the North American Data Model Steering Committee's Science Language Technical Team (SLTT) report on development of a proposed standard terminology for describing the lithology of rocks and sediments (2004; *http://pubs.usgs.gov/of/2004/1451/nadm/*). The SLTT report is the principal component of the NGMDB's lithology term list, which is part of the project's evolving set of science terminology standards (see Richard and Soller, this volume). This lithology term list then was reduced to a limited, more general set of terms appropriate for national and regional applications such as this Data Portal, where it serves as a principal attribute in the Portal's database. The restricted set of terms also was recently incorporated into the GeoSciML standard lithology terms and definitions (*https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/GeoSciML*).

The SLTT classification is a comprehensive, detailed, hierarchical list of terms and definitions. It serves as a useful compendium from which classifications can be tailored to suit a region's geology and the requirements of a map or Web-mapping system. Because the Data Portal shows an overview of the Nation's geology, its classification of geologic materials must concisely reflect the relative proportion of the various rock and sediment types found therein. In other words, the most commonly occurring materials must be classified or subdivided to a greater extent than those that are less common. To do otherwise would unduly emphasize relatively insignificant rock types at the expense of materials that cover broad expanses of the country. In a Web-mapping system in which cartographic display of map units on many separately published maps is quite technically challenging, this is especially important. In the conterminous U.S., sedimentary rocks underlie about 80 percent of the area (information derived from provisional database of Reed and others (2005) Geologic Map of North America). If surficial deposits were to be included in the estimate, the proportion of land underlain by sedimentary materials likely would be 90 percent or more. Further, given the relative heterogeneity of surficial materials and of interbedded sedimentary rocks as compared to other major rock types, and the fact that the majority of U.S. residents live on sediments or sedimentary rocks, it was imperative they be well represented in the Portal's classification by subdividing sedimentary materials to a greater extent than other rock types.

Geologic Materials Classification

General Process

There are three principal aspects to any classification: the names or terms, their definitions, and the structure within which they are organized. The first step taken was empirical – an inventory of the principal types of geologic materials and geologic map units encountered in the U.S. Next, these types were organized in a hierarchical classification according to principal criteria by which each particular class of materials commonly is classified. Through numerous iterations, the classification emerged (Appendix A provides a recent version). The current version is maintained at *http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/*; it includes the classification criteria, which could be used in structured searches. The final step in the classification process was to assign a name to each geologic material type, and to write its definition.

Based on the design principles and assumptions described above, the classification is:

- hierarchical and includes about 90 geologic material types,
- intended to characterize the general nature of the various geologic materials comprising each map unit shown on typical geologic maps,
- designed specifically for Web display of national- to regional-scale (e.g., 1:100,000) maps, and therefore may be inappropriate for more detailed maps,
- based mostly on familiar, commonly used terms, and
- supported by definitions intended for the general public.

The selection of names proved to be a difficult process in part because many names have ambiguous or multiple definitions, depending on the geologic context in which they are used and the geologist who is using them. Name selection was further complicated because of space limitations imposed by Web browsers. For example, the space available for a map legend at a website is, realistically, restricted to perhaps 1 - 2 inches in width. The traditional DMU must therefore be deconstructed – for example, a set of terse names in a map legend box might be supplemented by pop-up windows or mouseovers containing the full name and related information such as the name's definition, the map unit description, and geologic attributes (Figure 3 and Appendix B).

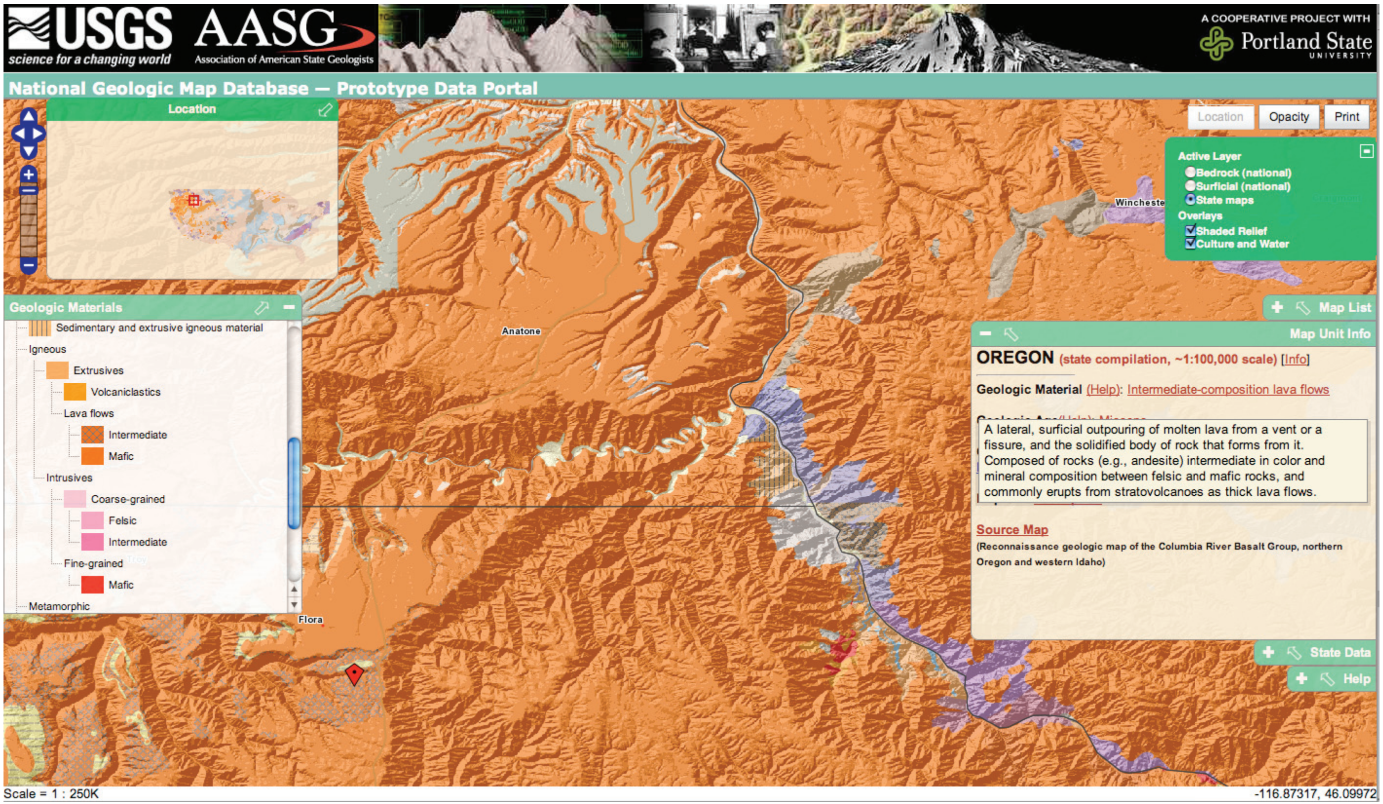


Figure 3. Screenshot of the NGMDB Data Portal, showing State-scale geologic map data of Washington, Oregon, and Idaho. Small red icon in lower left part of map marks location of a "MapUnitInfo" query, whose results are shown in pop-up box on right side of Portal window. The map unit's geologic material is named "Intermediate-composition lava flows"; the definition ("A lateral, surficial outpouring…") is obtained by mousing-over the name. The map unit is symbolized as hachured orange, and the name is shown in an abbreviated fashion in the hierarchical arrangement of the GeologicMaterials legend ("Igneous / Extrusives / Lava flows / Intermediate"). By mousing-over the abbreviated name "Intermediate," the full name "Intermediate-composition lava flows" is displayed. This approach was taken in order to restrict the legend to 1 – 2 inches in width and to provide the hierarchical context for each name.

What's a Good Definition?

For geologic material names used in this classification, definitions abound. Among the various definitions for a name, significant differences are not uncommon. In some cases these differences have a scientific basis, whereas in other cases they simply are a matter of scope or writing style. When writing a definition, authors carefully consider the intended audience and the format in which the definition will be presented. Clearly, in a general-interest publication or website, those definitions need to consist of more generalized terminology than might be useful for professional geologists; the definitions convey the general essence of name but may not be sufficiently precise for operational use by a field geologist. For example, "felsic" as defined for the public might describe the light color exemplified by the term, whereas the field geologist would be more interested in the specific minerals, the bulk chemistry, and the color index. The definitions in this classification are intended for the general public, for reasons stated above.

But definitions also must be written in a style appropriate to how they will be presented. For example, the definitions in the AGI Glossary (Neuendorf and others, 2005) are succinct and use terminology that may be unfamiliar. Nevertheless, because those terms also are contained in the Glossary, they may in turn be read and understood. A Web encyclopedia or glossary (e.g., see geologic terms in Wikipedia) uses the same strategy, with hyperlinks to related terms. This is an effective method for creating a concise yet informative definition. However, it is not always feasible or practical to use this approach, and in such cases the definitions must be more comprehensive. In the Data Portal, the definitions are intended for display when a user clicks on, or mouses-over, a name (Figure 3). Hyperlinks from such displays would be cumbersome for the user (not to mention, at least in our situation, the expense of software design), and so a "standalone" definition was needed.

Significant Decisions and Points of Contention

Here are brief comments on a few aspects of this classification and naming of geologic materials. These comments are not comprehensive but serve to indicate some of the significant decisions and points of contention. Comments are organized by geologic material classes or by classification criteria.

Clastic sediment – because the depositional environments and geomorphology of the various surficial materials have proven to be a common and reliable criteria for mapping and for delineation of map units, these materials do not neatly fit into classification schemes designed for rocks. For example, the ubiquitous map unit "alluvium," when classified in terms of lithologic-based criteria commonly applied to sedimentary rocks, might be generalized to simply "clastic sediment"; the fundamental nature and characteristics that we associate with "alluvium" are, so to speak, lost in translation. This classification therefore adopts terms that are in common use for describing and mapping surficial materials. However, two groups of these materials deserve further comment. First, although the term "Coastal zone sediment" is not uncommon as a general descriptor, it is not a familiar term in lithologic classifications. Based on a previous integration of surficial materials of the United States (Soller and Reheis, 2004), I found it useful to include here. Second, the names for mass movement deposits are unfamiliar. After much consideration, I chose these names because they seem clear and descriptive, but acknowledge that some users might not agree.

Clastic sedimentary rock – seldom is a geologic map unit, of any origin, composed solely of one lithology. In this group of rocks, multiple lithologies within a map unit can be particularly common and areally widespread, for example in the cyclothemic rocks deposited on the stable craton of the midcontinent. For this reason, and because sedimentary rocks cover a large area of the country, two geologic material types were defined specifically for map units that contain numerous lithologies. These two names are verbose, perhaps excessively so (Figure 4). However, the names are descriptive and use familiar terms. A third group of materials of this general type was identified, composed dominantly of carbonate rock interbedded with (clastic) sedimentary rock, and is classified under the parent, sedimentary rock.

○ **Mostly sandstone, interbedded with other sedimentary rocks which locally may include conglomerate and finer grained clastics (mudstone), carbonates, and/or coal** -- This area is underlain by sequences of various sedimentary rocks that, for this generalized map depiction, are too complex to be shown separately.

Figure 4. A clastic sedimentary rock such as the Tradewater Formation (Figure 2) is composed of various geologic materials and not distinctly dominated by any one. These rock types are common throughout the United States, especially in the Mississippian-Pennsylvanian and Cretaceous. Rather than name these rocks according to a term that has strong geologic-process connotation (e.g., cyclothem) that may not apply to all rocks of this type, it was decided to simply name it according to its common constituents.

Felsic-, Intermediate-, and Mafic-composition igneous rocks – the bulk composition of igneous rocks and the minerals of which they are composed, as well as the resulting rock color, commonly have been a basis for classification. For example, the terms felsic, intermediate, and mafic composition (emphasizing the color of the rock and predominant minerals), or acidic, intermediate, and basic (emphasizing the bulk chemistry). Both classification systems are widely used. Geologists describing extrusive rocks seem to prefer the chemistry-based names. For all igneous rocks I opted for the mineral composition and color-based system, which I sense is somewhat more widely used and familiar. Differences of opinion exist in the literature regarding whether certain rocks (e.g., syenite, dacite) should be classified as felsic or intermediate, but the dominant usage seems to be felsic and is so reflected in the classification.

Fine-grained intrusive igneous rock, *Mafic-composition air-fall tephra, and Felsic-composition lava flows* – the classification strives to restrict the number of rock and sediment types, for reasons discussed above. However, for the sake of parallel construction, these three relatively uncommon rock types were included.

Applying the Classification

Dynamic Reclassification and Symbolization

The classification includes about 90 types of geologic materials. Displaying all of these on a traditional map and DMU is feasible. But in a Web-mapping system it is far too cumbersome – when a map is displayed in a browser, the user struggles to comprehend complex geologic map patterns. Aggregation of map units, into perhaps 10-20 geologic materials classes, is more appropriate for Web display. This presents a technical challenge because the user specifies the map area to be shown. To most effectively display the geology each time the user pans or zooms, the system should dynamically change the aggregation scheme, the DMU, and the symbolization.

This first iteration of the NGMDB Data Portal approximates that goal by generating different aggregation schemes and symbolizations for various types of maps shown (e.g., national maps, State maps) and for the various levels of detail of a given map that are shown as the user zooms in or out. In future iterations, we anticipate addressing differences in aggregating and symbolizing among geologic regions.

Currently, the system functions as follows:

- The initial view is of a national bedrock or surficial geologic map, at 1:15 million scale. The aggregation scheme for each map emphasizes the (approximately) 10 most areally extensive geologic material classes.

- The first level of display detail (1:7.5 million scale) uses a somewhat less extensive aggregation of the 90 material types. As noted, in the future we intend to vary the aggregation regionally, but for this version we strove for a single scheme that results in perhaps 20 or fewer material types displayed for any given map area. As the user pans across the U.S., the symbolization remains fixed but the DMU or map legend is updated dynamically to show only the geologic materials that actually occur within the field of view.
- At more detailed levels of display (1:3 million and 1:1.5 million) the full classification is used without aggregation. At these levels, the user is given the option to view State-level geologic mapping instead of the national-scale maps. Symbolization of the State maps is somewhat different than for the national maps, and is reflected in the map legend.
- Additional levels of zoom are provided, but because generally they exceed the compilation scale of State geologic maps, the option is provided to access more detailed geologic maps via the NGMDB Map Catalog.

Simple and Clear Presentation

Web presentation of information is a relatively new issue, and with it new challenges have arisen. In the NGMDB Data Portal we address some of these, within the very real limits of our experience, artistic judgment, and funding. Our focus has been the timeless need for simple, clear presentation of generalized geologic information, adapted to a relatively new medium. Suggestions for improved clarity are welcomed.

Acknowledgments

Foremost, I humbly thank the geologists who, in years past, attempted to create order from seeming chaos. Struggling to define this classification, I have even more respect for their intellectual exertions and classifications. I also gratefully acknowledge these NGMDB project members: David Percy (Portland State University), who focused on implementation of the Data Portal itself as well as provided advice and guidance during the process of classifying; Morgan Harvey (Portland State University), for his software development work on the Portal, specifically the dynamic legend; Stephen Richard (Arizona Geological Survey), who provided significant advice and suggestions on classification and definitions; and Nancy Stamm (USGS), who significantly advised me on classification systems in general, and in particular the imperative for simple and clear terminology. Finally, I thank David Sherrod (U.S. Geological Survey) for his scientific expertise and for his guidance in classifying the volcanic rocks; the resulting classification benefited greatly from my opportunity to obtain his views, but responsibility (or blame) for the result rests with me.

References

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

Nelson, W.J., 1998, Bedrock geology of the Paducah 1° x 2° CUSMAP quadrangle, Illinois, Indiana, Kentucky, and Missouri: U.S. Geological Survey Bulletin 2150-B, 36 p., 1 map, scale 1:250,000, *http://ngmdb.usgs.gov/Prodesc/proddesc_19757.htm*.

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 four Appendices (online version only), *http://pubs.usgs.gov/of/2004/1451/nadm/*.

Powell, J.W., 1888, Methods of geologic cartography in use by the United States Geological Survey, *in* Congrès Géologique International, Compte Rendu de la 3me Session, Berlin, 1885: A.W. Schade's Buchdruckerei, Berlin, p. 221–40.

Reed, J.C., Jr., Wheeler, J.O., and Tucholke, J.E., compilers, 2005, Geologic map of North America: Decade of North American Geology Continental Scale Map 001, Boulder, Geological Society of America, scale 1:5,000,000, *http://rock.geosociety.org/bookstore/default.asp?oID=0&catID=2&pID=CSM001F*.

Soller, D.R., 2008, The National Geologic Map Database Project – 2007 Report of Progress, *in* Soller, D.R., ed., Digital Mapping Techniques '07 – Workshop Proceedings: U.S. Geological Survey Open-file Report 2008-1385, p. 11-20, *http://pubs.usgs.gov/of/2008/1385/pdf/soller.pdf*.

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://ngmdb.usgs.gov/Prodesc/proddesc_19757.htm*.

Appendix A. Terms and Definitions for the NGMDB Geologic Materials Classification

The terms in this classification are intended to describe a geologic map unit as a whole. The classification is not intended for application to separate, lithologically distinct bodies of rock or sediment that may be observable but undifferentiated, within a map unit. It is designed for display of regional- and national-scale geologic maps in applications such as the National Geologic Map Database's Data Portal (*http://maps.ngmdb.us/dataviewer/*), and so may be inappropriate for use with more detailed maps. The definitions are intended for the general public as well as for geologists (see source for definitions, at end of this Appendix). The current version of this classification is maintained at *http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/*; it includes the classification criteria, which could be used in structured searches.

- **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.
            - **Clastic sediment of unspecified origin** -- 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 (e.g., 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.

o **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.

o **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.

o **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.

o **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.

o **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 of geologic materials, downslope** -- 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; e.g., 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.

o **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, interbedded with other sedimentary rocks which locally may include conglomerate and finer grained clastics (mudstone), carbonates, and/or coal** -- This area is underlain by sequences of various sedimentary rocks that, for this generalized map depiction, are too complex to be shown separately.
    - **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, interbedded with other sedimentary rocks which locally may include coarser grained clastics (sandstone, conglomerate), carbonates, and/or coal** -- This area is underlain by sequences of various sedimentary rocks that, for this generalized map depiction, are too complex to be shown separately.
    - **Carbonate rock** -- A sedimentary rock such as limestone or dolomite, consisting chiefly of carbonate minerals.
    - **Mostly carbonate rock, interbedded with clastic sedimentary rock** -- This area is underlain by sequences of various sedimentary rocks that, for this generalized map depiction, are too complex to be shown separately.
    - **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 (i.e., 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** -- An avalanche of hot ash, pumice, rock fragments, and volcanic gas that rushes down the side of a volcano as fast as 100 km/hour or more. Once deposited, the ash, pumice, and rock fragments may deform (flatten) and weld together because of the intense heat and the weight of the overlying material.
                - **Felsic-composition pyroclastic flows** -- An avalanche of hot ash, pumice, rock fragments, and volcanic gas that rushes down the side of a volcano as fast as 100 km/hour or more. Once deposited, the ash, pumice, and rock fragments may deform (flatten) and weld together because of the intense heat and the weight of the overlying material. Composed of light-colored rocks (e.g., rhyolite, dacite) which, because of their high-silica content and resulting high viscosity, tend to erupt explosively.
                - **Intermediate-composition pyroclastic flows** -- An avalanche of hot ash, pumice, rock fragments, and volcanic gas that rushes down the side of a volcano as fast as 100 km/hour or more. Once deposited, the ash, pumice, and rock fragments may deform (flatten) and weld together because of the intense heat and the weight of the overlying material. Composed of rocks (e.g., 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** -- An avalanche of hot ash, pumice, rock fragments, and volcanic gas that rushes down the side of a volcano as fast as 100 km/hour or more. Once deposited, the ash, pumice, and rock fragments may deform (flatten) and weld together because of the intense heat and the weight of the overlying material. Composed of dark-colored rocks (e.g., 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 blasted into the air by explosions or carried upward 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 blasted into the air by explosions or carried upward 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 (e.g., rhyolite, dacite) 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 blasted into the air by explosions or carried upward 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 (e.g., 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 blasted into the air by explosions or carried upward 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 (e.g., 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 (e.g., 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 (e.g., 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 (e.g., rhyolite, dacite) which, because of their high-silica content and resulting high viscosity, tend to erupt explosively, and so these deposits are uncommon.
        - **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 (e.g., andesite) intermediate in color and mineral composition between felsic and mafic rocks, and commonly erupts from stratovolcanoes as thick lava flows.
        - **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 (e.g., basalt), and tends to form extensive sheets with generally low relief. Includes basaltic shield volcanoes, which may become very large (e.g., Hawaii).
- **Intrusive igneous rock** -- Rock that solidified from molten or partly molten material (i.e., magma), forming below the Earth's surface.
    - **Coarse-grained intrusive igneous rock** -- Rock that solidified from molten or partly molten material (i.e., 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 (i.e., 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 (e.g., quartz, feldspars, feldspathoids, muscovite). Includes granitic and syenitic rock.
        - **Coarse-grained, intermediate-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (i.e., 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 (i.e., 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 one or more ferromagnesian, dark-colored minerals. Includes gabbroic rock.
        - **Ultramafic intrusive igneous rock** -- Rock that solidified from molten or partly molten material (i.e., 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, e.g., monomineralic rocks composed of hypersthene, augite, or olivine.
    - **Fine-grained intrusive igneous rock** -- Rock that solidified from molten or partly molten material (i.e., 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 (i.e., 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 (e.g., quartz, feldspars, feldspathoids, muscovite). Includes rhyolitic, dacitic, and trachytic rock.
        - **Fine-grained, intermediate-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (i.e., 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 (i.e., 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 one or more ferromagnesian, dark-colored minerals. Includes basaltic rock.
    - **Exotic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (i.e., 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. This area is not dominantly either igneous or metamorphic.
- **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 (e.g., igneous, sedimentary) is not known.

        - **Medium and high-grade regional metamorphic rock, of unspecified origin** -- A rock which is 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 (e.g., igneous, sedimentary) 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 (e.g., 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**

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 Team, 2007, Science vocabulary to support the National Geologic Map Database project: Lithology terms: U.S. Geological Survey unpublished document, 218 p., available at *http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/*.

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, U.S. Geological Survey Volcano Hazards Program website, *http://volcanoes.usgs.gov/images/pglossary/index.php*.

Appendix B. Terse, Hierarchical Notation Shown in Map Legend, and the Corresponding Full Names

The terse names are necessitated by the page-size limitations imposed by the Web browser. These names are placed in the context by the hierarchical display, and comprehension is supported by the display of full names within the Data Portal's query results (Figure 3).

Terse, hierarchical notation shown in Map Legend	Full name, as shown in query results and definition
Sedimentary	Sedimentary material
Sediment	Sediment
Clastic sediment	Clastic sediment
Unspecified origin	Clastic sediment of unspecified origin
Sand, gravel	Sand and gravel of unspecified origin
Silt, clay	Silt and clay of unspecified origin
Alluvium	Alluvial sediment
Mostly coarse-grained	Alluvial sediment, mostly coarse-grained
Mostly fine-grained	Alluvial sediment, mostly fine-grained
Glacial till	Glacial till
Mostly sandy	Glacial till, mostly sandy
Mostly silty	Glacial till, mostly silty
Mostly clayey	Glacial till, mostly clayey
Ice-marginal	Ice-contact and ice-marginal sediment
Mostly coarse-grained	Ice-contact and ice-marginal sediment, mostly coarse-grained
Mostly fine-grained	Ice-contact and ice-marginal sediment, mostly fine-grained
Eolian	Eolian sediment
Sand	Dune sand
Loess	Loess
Lacustrine	Lacustrine sediment
Mostly coarse-grained	Lacustrine sediment, mostly coarse-grained
Mostly fine-grained	Lacustrine sediment, mostly fine-grained
Playa	Playa sediment
Coastal zone	Coastal zone sediment
Mostly coarser grained	Coastal zone sediment, mostly coarser grained
Mostly fine-grained	Coastal zone sediment, mostly fine-grained
Marine	Marine sediment
Mostly coarser grained	Marine sediment, mostly coarser grained
Mostly fine-grained	Marine sediment, mostly fine-grained
Mass movement	Mass movement of geologic materials, downslope
Widespread	Colluvium and other widespread mass-movement sediment
Localized	Debris flows, landslides, and other localized mass-movement sediment
Residual	Residual material
Carbonate	Carbonate sediment
Peat	Peat and muck
Rock	Sedimentary rock
Clastic rock	Clastic sedimentary rock
Conglomerates	Conglomerate
Sandstones	Sandstone
Mostly sandstone	Mostly sandstone, interbedded with other sedimentary rocks which locally may include conglomerate and finer grained clastics (mudstone), carbonates, and/or coal
Sandstone and mudstone	Sandstone and mudstone
Mudstones	Mudstone

Mostly mudstone	Mostly mudstone, interbedded with other sedimentary rocks which locally may include coarser grained clastics (sandstone, conglomerate), carbonates, and/or coal
Limestones	Carbonate rock
Mostly limestones	Mostly carbonate rock, interbedded with clastic sedimentary rock
Evaporites	Evaporitic rock
Iron-rich	Iron-rich sedimentary rock
Coal	Coal and lignite
Sedimentary and extrusive igneous material	Sedimentary and extrusive igneous material
Igneous	Igneous rock
Extrusives	Extrusive igneous material
Volcaniclastics	Volcaniclastic (fragmental) material
Pyroclastic flows	Pyroclastic flows
Felsic	Felsic-composition pyroclastic flows
Intermediate	Intermediate-composition pyroclastic flows
Mafic	Mafic-composition pyroclastic flows
Air-fall tephra	Air-fall tephra
Felsic	Felsic-composition air-fall tephra
Intermediate	Intermediate-composition air-fall tephra
Mafic	Mafic-composition air-fall tephra
Lava flows	Lava flows
Felsic	Felsic-composition lava flows
Intermediate	Intermediate-composition lava flows
Mafic	Mafic-composition lava flows
Intrusives	Intrusive igneous rock
Coarse-grained	Coarse-grained intrusive igneous rock
Felsic	Coarse-grained, felsic-composition intrusive igneous rock
Intermediate	Coarse-grained, intermediate-composition intrusive igneous rock
Mafic	Coarse-grained, mafic-composition intrusive igneous rock
Ultramafic	Ultramafic intrusive igneous rock
Fine-grained	Fine-grained intrusive igneous rock
Felsic	Fine-grained, felsic-composition intrusive igneous rock
Intermediate	Fine-grained, intermediate-composition intrusive igneous rock
Mafic	Fine-grained, mafic-composition intrusive igneous rock
Exotics	Exotic-composition intrusive igneous rock
Igneous and metamorphic rock	Igneous and metamorphic rock
Metamorphic	Metamorphic rock
Unspecified origin	Regional metamorphic rock, of unspecified origin
Medium to High-grade	Medium and high-grade regional metamorphic rock, of unspecified origin
Contact	Contact-metamorphic rock
Deformation	Deformation-related metamorphic rock
Metasedimentary	Metasedimentary rock
Slate and phyllite	Slate and phyllite, of sedimentary rock origin
Schist and gneiss	Schist and gneiss, of sedimentary rock origin
Marble	Marble
Quartzite	Quartzite
Metaigneous	Metaigneous rock
Rock and sediment	Rock and sediment
Rock	Rock
“Made” land	“Made” or human-engineered land
Water or ice	Water or ice
Unmapped	Unmapped

Kentucky Field Data Entry Tools Developed in ArcIMS

By Gerald A. Weisenfluh and Douglas C. Curl

Kentucky Geological Survey
228 Mining and Mineral Resources Bldg.
University of Kentucky
Lexington, KY 40506-0107
Telephone: (859) 257-5500
Fax: (859) 257-1147
email: {*jerryw*, *doug*}*@uky.edu*

Introduction

Between 1996 and 2006, under the National Cooperative Geologic Mapping Program's STATEMAP program, the Kentucky Geological Survey's (KGS) digital mapping program compiled 707 geologic quadrangle maps into a seamless spatial database of geologic information for the State. These maps, originally published between 1960 and 1978, focus primarily on the bedrock geology of Kentucky—Paleozoic and Mesozoic sedimentary rocks. Delineation of unconsolidated deposits was only done in a generalized manner. These geologic data now support an Internet-based map service (Weisenfluh and others, 2005) that allows users to create customized geologic maps with overlays of a variety of related geoscience data maintained in KGS databases. Geologic map unit descriptions from the collars of the maps were also digitized into a database and can be accessed from the map and other searchable Web pages.

Once the digital compilation was complete, KGS shifted its STATEMAP effort to mapping the unconsolidated deposits of the State to support a variety of research activities related to land use and natural hazards mitigation. One of the products of this new mapping will be an additional geologic layer to overlie the bedrock geologic units. Two separate database needs have arisen as a result of this new activity. First, field geologists need to review existing well databases prior to mapping, in order to assess depth to bedrock and unconsolidated lithology recorded for those sites. This can be an extremely time-consuming activity given the large numbers of water, oil, gas, geotechnical, and coal exploration holes drilled in Kentucky. Second, as geologists collect new field data during mapping, it has become desirable to catalog that information in institutional databases to facilitate map preparation and to preserve data for future workers. This paper describes two Web-based ArcIMS programs developed to address these geospatial database problems.

Harvesting Well Databases To Support Surficial Mapping

The challenge of utilizing well information from a variety of sources in order to assess unconsolidated materials arises from differing qualities of data and differing formats for recording it. Data quality is affected by accuracy of the recorded location and elevation, method of drilling, and the experience and care of the personnel recording the information. In general, the quality of lithology descriptions is better for geotechnical and water wells than for coal drill holes or oil and gas wells. The latter industries are not overly concerned with the composition of the surficial material, but merely need to case through it to prevent open-hole caving. However, there is also variability among wells of a given type that is dependent on the operator or their purpose. There are also differences in how KGS has digitized the records from each type of well.

For water wells and coal exploration holes, subsurface data have been entered into tabular databases for efficient retrieval. Oil and gas drillers' logs are scanned into an electronic image format, and most geotechnical hole information is only found on illustrations of project reports in PDF documents.

Application Requirements

Because the data review prior to geologic mapping involves a qualitative assessment of parts of existing documents containing well data, it was deemed necessary to preserve the results of the review in a new database. New tables were created to store information specific to depth to bedrock measures and lithologic character of the unconsolidated material. Individual geologists typically review data beyond the limits of the quadrangle being mapped; therefore, a way of denoting whether a specific well has already been interpreted was needed to eliminate duplication of effort when adjoining quadrangles are mapped. The application needed to be able to display the various formats of data under review and to extract parts of the legacy data into the new tables to eliminate redundant data entry. Finally, the site locations had to be viewed on a topographic map base so that elevation data in the database could be reconciled with topography.

Application Design

The data harvesting tool was designed as a customized ArcIMS Internet map service. The program uses the ESRI ActiveX connector to facilitate customized controls and database connectivity using Active Server Pages (ASP) scripting with Javascript and DHTML. The ArcIMS choice was primarily driven by the need to dynamically display site locations from a tabular database on a map, and because of previous experience with the same development environment. Both the source and destination database tables are located in the KGS enterprise SQLServer database. The map service was intended only for internal staff use, and therefore is protected by user login functionality. However, because it is a Web-based application, it can be accessed from any computer that can connect to the Internet, so that staff could use the application while in the field.

Geologists preferred to review one well type at a time, because of the different methods of processing each kind. The application contains a control to specify the quadrangle of interest and the well type for properly initializing the program. The application form (Figure 1) has four fixed windows. The upper left corner contains the map view that shows the locations of all existing wells of each type, along with a number of controls for managing the view extent and scale. The upper right window contains the controls to log in and specify area and well type of interest (not visible on Figure 1) and a list of wells of the specified type with controls to zoom to a site and to display and edit information for each well. The icons in the two leftmost columns indicate whether the record has already been reviewed. If data have previously been extracted for a well, the "show" and "del" buttons appear in the second column. When the "no data" message appears in the first column, it indicates that the record has been reviewed but contained no useful information for this purpose. Those records that only show the "view/edit" button have never been reviewed. The lower left window is used to display information about the selected well. This window usually contains tabular listings of well characteristics but may also contain images of documents, such as casing reports, drillers' logs, and geophysical logs. The lower right window is the data entry form (blank in Figure 1—see Figure 3 for an example) where harvested data are sent, and along with user additions are submitted to the new database. The interaction between the data display form and the data entry form depend on the well type and its associated data.

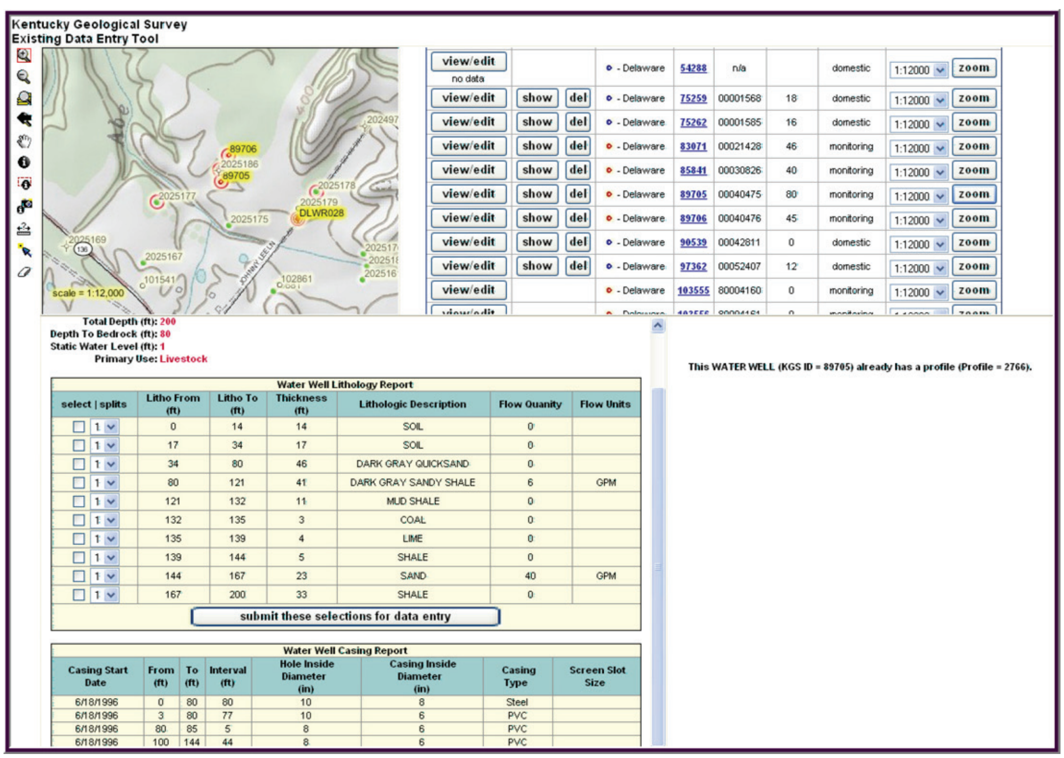


Figure 1. The main page of the KGS well data harvesting tool, showing an example display for water wells.

Processing Oil and Gas Wells

The KGS oil and gas database is structured so that information describing the well is stored in tabular form, but the details of subsurface intervals typically are not. Those data can be found in various documents that are submitted after well completion; these have been scanned and compiled into online image files. The only relevant information that can be directly harvested from the tabular database is the surface elevation—all other information must be manually entered after reviewing the available documents. Once the view/edit button is selected for a particular well, its documents are displayed in the lower left window. The geologist reviews both the driller's log (Figure 2) and the casing report to make a determination of depth to bedrock and the thickness and composition of one or more intervals of unconsolidated material. The number of lithologic intervals is then specified at the top of the right panel (Figure 2), which then builds a data entry form with the corresponding number of records (Figure 3) in the same window. The lithology type, description, and interval footages are manually entered into the form, and any comments relevant to the entry are added before the data are committed to the Quaternary database.

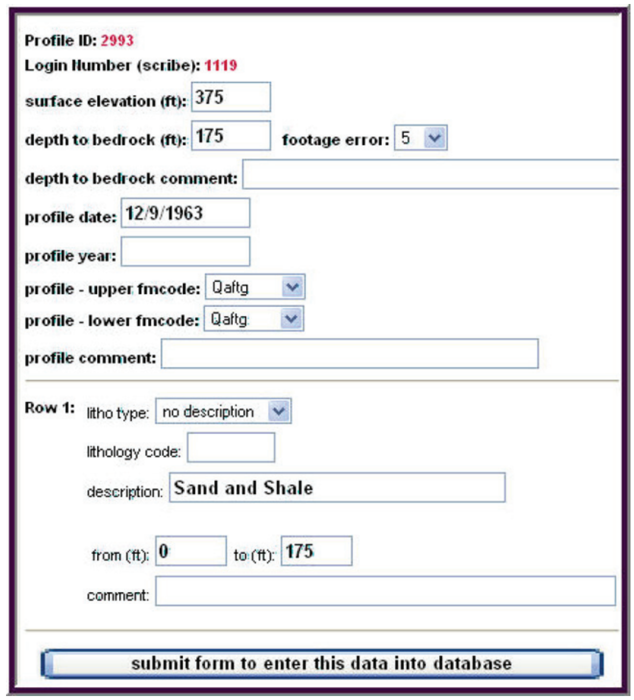


Figure 3. Example data entry form for oil and gas well, found in lower right part of the well data harvesting tool.

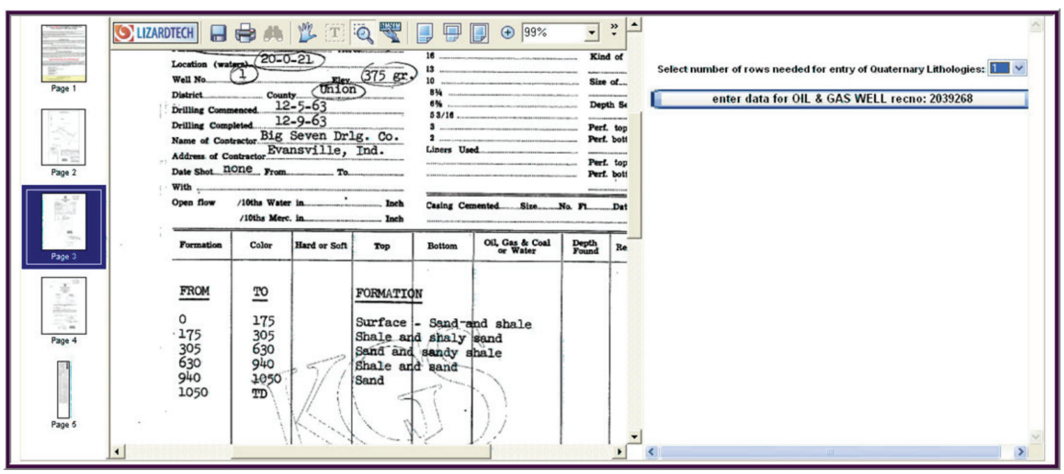


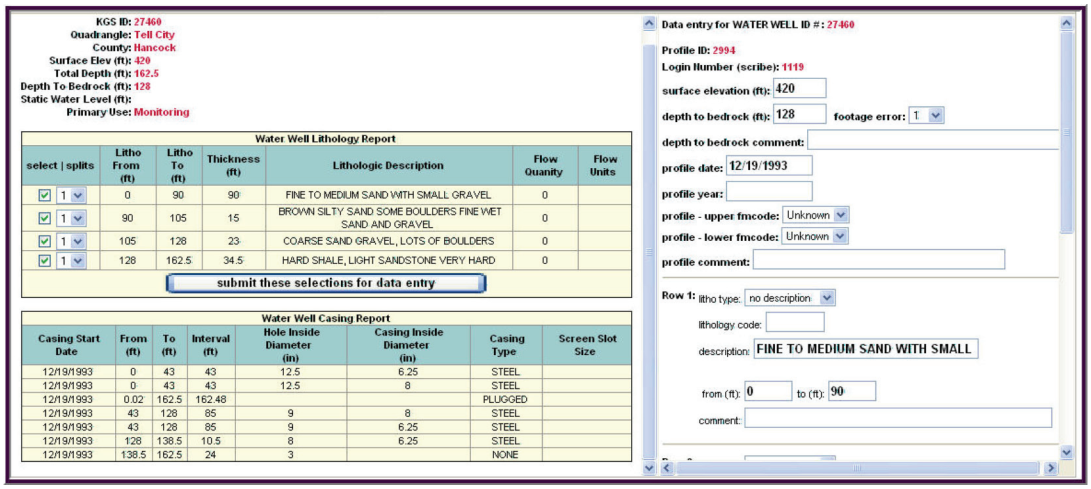
Figure 2. Lower half of application screen showing image of an oil and gas driller's log in display window (left) and control to initiate the correct number of interval entries (right).

Processing Water Wells and Coal Exploration Wells

Unlike the database for oil and gas wells, the KGS water well and coal borehole databases contain tabular records of subsurface sediment and rock lithologies. For these well types, the existing database information is shown in the display window (Figure 4). The user only has to select which entries pertain to unconsolidated materials by checking the appropriate lines. In some cases, a single database entry may describe more than one lithology, and the option is presented to split the interval into two or more lines. Once these selections are submitted, the data entry form is constructed with the correct number of records and each is pre-populated with interval footages and lithology terms. The user only has to set the lithology type (sediment, rock, or artificial material) and enter footages for any split intervals.

Quaternary Database

The output of this program adds information to three database tables. Summary information about the well is first



KGS ID: 27460
Quadrangle: Tell City
County: Hancock
Surface Elev (ft): 420
Total Depth (ft): 162.5
Depth To Bedrock (ft): 128
Static Water Level (ft):
Primary Use: Monitoring

Water Well Lithology Report

select | splits	Litho From (ft)	Litho To (ft)	Thickness (ft)	Lithologic Description	Flow Quanity	Flow Units
1	0	90	90	FINE TO MEDIUM SAND WITH SMALL GRAVEL	0	
1	90	105	15	BROWN SILTY SAND SOME BOULDERS FINE WET SAND AND GRAVEL	0	
1	105	128	23	COARSE SAND GRAVEL, LOTS OF BOULDERS	0	
1	128	162.5	34.5	HARD SHALE, LIGHT SANDSTONE VERY HARD	0	

submit these selections for data entry

Water Well Casing Report

Casing Start Date	From (ft)	To (ft)	Interval (ft)	Hole Inside Diameter (in)	Casing Inside Diameter (in)	Casing Type	Screen Slot Size
12/19/1993	0	43	43	12.5	6.25	STEEL	
12/19/1993	0	43	43	12.5	8	STEEL	
12/19/1993	0.02	162.5	162.48			PLUGGED	
12/19/1993	43	128	85	9	8	STEEL	
12/19/1993	43	128	85	9	6.25	STEEL	
12/19/1993	128	138.5	10.5	8	6.25	STEEL	
12/19/1993	138.5	162.5	24	3		NONE	

Data entry for WATER WELL ID #: 27460
Profile ID: 2994
Login Number (scribe): 1119
surface elevation (ft): 420
depth to bedrock (ft): 128 footage error: 1
depth to bedrock comment:
profile date: 12/19/1993
profile year:
profile - upper fmcode: Unknown
profile - lower fmcode: Unknown
profile comment:
Row 1: litho type: no description
lithology code:
description: FINE TO MEDIUM SAND WITH SMALL
from (ft): 0 to (ft): 90
comment:

Figure 4. Data display and entry form for water well. Upper part of data entry form has information about the site, and the lower part has successive entry sections for each lithology interval.

added to a site description table that describes the location and context of geologic observations. Another entry is made to a table where bedrock depth and an assessment of the accuracy of the value are documented. These data are extracted, imported to GIS, and contoured prior to conducting fieldwork. Finally, one or more records of subsurface materials are added to a Quaternary lithology table for assessing the stratigraphy of unconsolidated units in the map area.

Field Data Entry Application

Once fieldwork had commenced, geologists needed a mechanism of cataloging site descriptions, field observations, samples, measurements, and photographs. The KGS database has the capability of treating many of these elements individually, but there was not a single computer application that streamlined the process of data entry—a long-term impediment to institutionalizing valuable information. There also was a need to associate the various kinds of information, stored in separate database structures, according to the site of collection and the author. This issue is easy to address at the database level but difficult to implement when using separate data entry applications for each kind of information. A tool for entering field data was developed to accommodate these needs.

Like the data harvesting tool, the field data tool is an ArcIMS application with similar layout (Figure 5). It has a map frame to view the locations of both harvested wells and other kinds of field sites. A list of sites shown on the map frame (lower right corner of Figure 5) is created dynamically as the user pans the map. This list shows the type of site (e.g., outcrop, landform, water well), indicates by yellow highlighting if the current user created the site in the system, shows icons to indicate the kinds and numbers of data that have been cataloged for the site, and provides controls for zooming to a site and adding more information to the catalog. The lower left corner of the application frame contains a number of functions for adding different kinds of field data to the system for the selected site. The upper right hand corner has a function to upload a GPS waypoint file to simplify the process of establishing sites.

Creating Field Site Entries

When a user logs into the application and zooms to an area of interest, the map shows any existing sites that have been previously created, by any registered user, which may or may not have associated field data. The sites are generic; that is, they are not associated with a particular staff member, and so if the geologist has visited one of these existing localities, they can add their information to it. Otherwise, a new site must be created. There are several means of adding new sites. The first is to manually enter a coordinate value for the location. This tool (pencil icon on left side of map) permits the coordinate to be entered in any valid projection and datum. The second method is to use a map tool (blue arrow on left side of map) to digitize a point on the map so that the system can calculate the coordinates. The final, and most efficient method is to upload a waypoint coordinate file obtained from a GPS device. When this method is used, a list of waypoints is constructed and displayed immediately below the waypoint upload button. The user can sequentially focus the map on each waypoint, validate its location, and add it to the lower site list so that field data can be entered. When a new site is added, an entry form is provided to describe the type of locality, its geologic context, and other locale information such as a roadway milepoint designation for an outcrop.

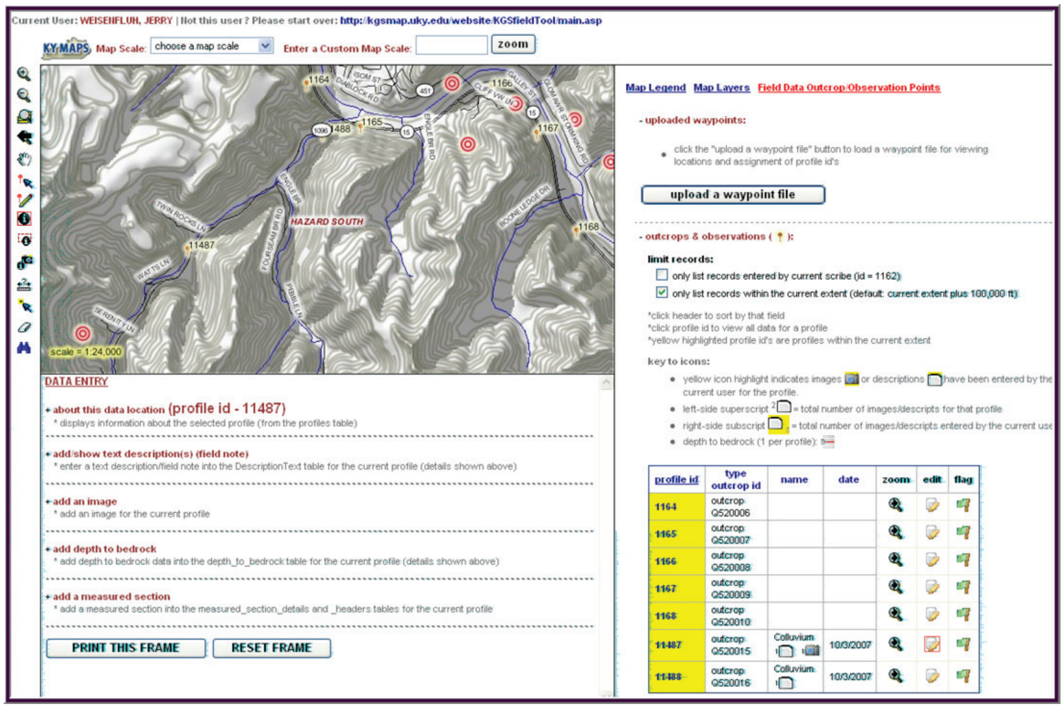


Figure 5. The main page of the KGS tool for entering field data.

Adding Data to Field Sites

Individual tools are provided for adding each specific kind of field data to a site; these tools are available on the left side of the field data-entry tool (Figure 5). At the present time, users can add text descriptions (field notes), depth to bedrock measurements, and photographs. To enter a field note (Figure 6), a description category must be selected from a pull-down menu (e.g., lithology, landform, geotechnical) and one or more geologic unit names ("fmcode") can be assigned, if applicable. KGS uses AAPG-style codes for stratigraphic units and these standard codes can be looked up using the "Display Fmcode Finder" link. The note is entered as free text in the description text box. Field notes inherit the location of the site by default. However, if several observations from a single site are made, each can be assigned its own coordinate location because sites may be large enough to encompass several point location observations. The user can choose to keep a note private (i.e., not accessible to the general public) while the project is under way, or in cases where the context of the information would not be useful to other parties. Entering depth to bedrock information is equally simple (Figure 7). Users enter the surface elevation of the site, the depth to bedrock in feet, a code qualifying the accuracy of the measurement, and any comments. This function would be used to document observations of bedrock exposure and shallow bedrock depths obtained by rod or auger soundings.

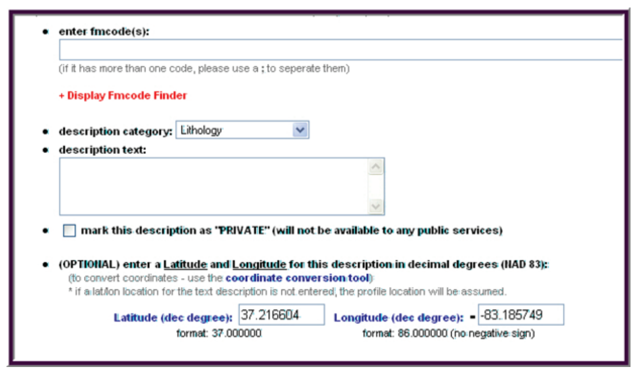


Figure 6. Data-entry form for field note or other text description.

Photos or other images, such as drawings, cross sections, or diagrams, can be added using a preexisting data entry application (Weisenfluh and Curl, 2007). Image files are uploaded to a Web server, can be overprinted with credit text, and fully attributed with captions and keywords. This field data application links to the photo application and passes the user's authentication and site identifier to that program to maintain these key relationships.

Other data entry applications are under development for adding documents (data files or reports), measured sections, and sample descriptions of rock, liquid, or gas to a site.

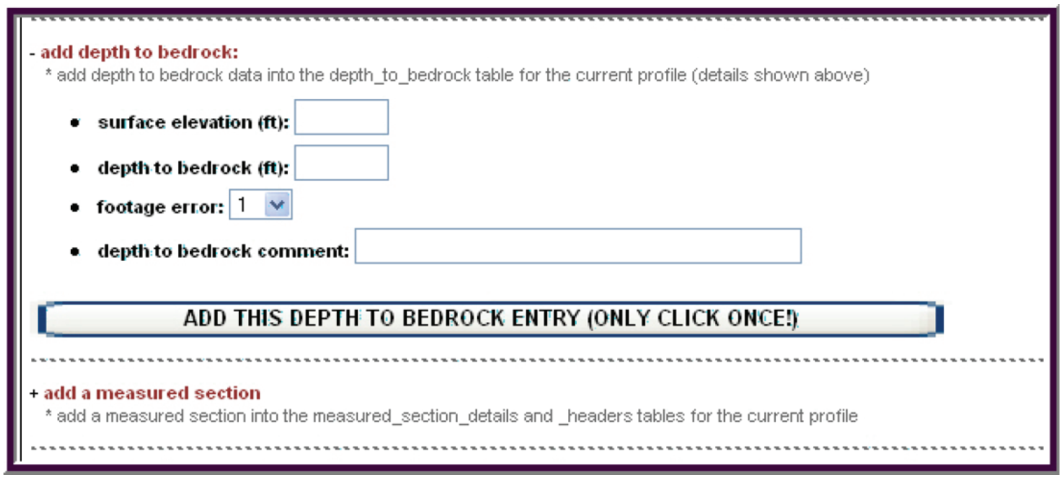


Figure 7. Data-entry form for depth to bedrock measurement.

Accessing Field Data

One of the main advantages of entering field data into an enterprise database is the increased accessibility of the information to the researcher, but also to others who would benefit from it. The last 1:24,000-scale bedrock geologic map for Kentucky was published in 1978, and KGS still regularly receives requests for station maps and field notebooks. Unfortunately, most of the latter remained in the possession of the authors. Unless current mappers elect to mark field notes as "private," the information is available on the KGS Web site as soon as it is submitted. The decision to release data is made by the geologist and is guided by the question of whether the information is generally useful to other practitioners. There are two ways that the data can be discovered by the public. The first is Web-based search forms specific to each kind of data (*http://kgsweb.uky.edu/main.asp*). One service is used to find photographs and other images by geographic and keyword criteria. The other service is a geologic description search page that returns published descriptions from geologic maps as well as field notes or other unpublished text descriptions. The results of these queries are sorted by source and map scale for published materials and by author for unpublished data. The search results also show a statewide geologic map with quadrangles highlighted where the search term was found. The user can identify these quadrangles and link to a detailed geologic map with the specific geologic units highlighted.

The second method of finding field data is to view the KGS geologic map service (*http://kgsmap.uky.edu/website/KGSGeology/viewer.asp*) for an area of interest. The map (Figure 8) can be formatted by the user to display field sites, photograph locations, and wells of any type, and the associated information for these localities can be accessed using tools provided on the map.

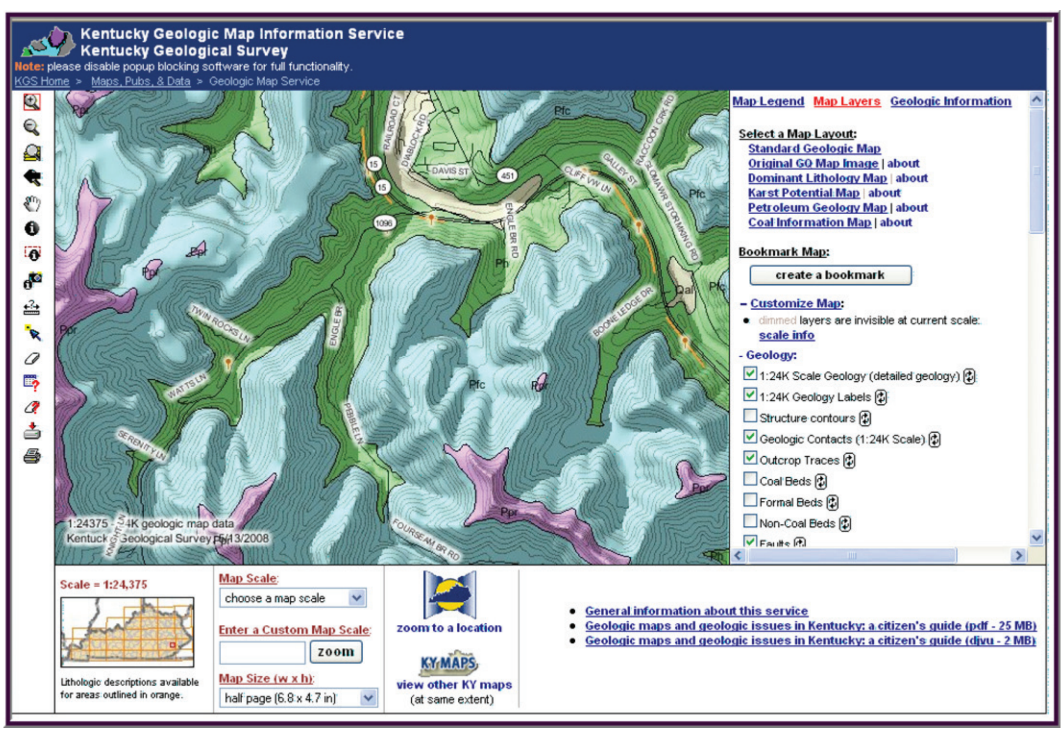


Figure 8. Example KGS geologic map service showing field sites as push pins.

References

Weisenfluh, G.A., and Curl, D.C., 2007, Unpublished geologic evidence and other databases of the Kentucky Digital Mapping Program, *in* Soller, D.R., ed., Digital Mapping Techniques '06 – Workshop Proceedings: U.S. Geological Survey Open-File Report 2007-1285, p. 101-106, *http://pubs.usgs.gov/of/2007/1285/pdf/Weisenfluh.pdf*. (See also *http://ngmdb.usgs.gov/Info/dmt/docs/weisenfluh06.ppt* for presentation, and *http://kgsweb.uky.edu/geology/image_search.asp* for Internet service.)

Weisenfluh, G.A., Curl, D.C., and Crawford, M.M., 2005, The Kentucky Geological Survey's online geologic map and information system, *in* Soller, D.R., ed., Digital Mapping Techniques '05 – Workshop Proceedings: U.S. Geological Survey Open-File Report 2005-1428, p. 5-10, *http://pubs.usgs.gov/of/2005/1428/weisenfluh/index.html*. (Internet service available at *http://kgsmap.uky.edu/website/KGSGeology/viewer.asp*.)

Defining a Three-Dimensional Geologic Map for the Appalachian Plateau

By Gayle H. McColloch, Jr. and Jane S. McColloch

West Virginia Geological and Economic Survey
1 Mont Chateau Road
Morgantown, WV 26508-8079
Telephone: (304) 594-2331
Fax: (304) 594-2575
email: *mccolloch@geosrv.wvnet.edu*, *janemc@geosrv.wvnet.edu*

Introduction

The West Virginia Geological and Economic Survey (WVGES) was introduced to geographic information systems (GIS) in the early 1980s when the venerable SYMAP package from the Harvard Laboratory for Computer Graphics and Spatial Design (Dougenik and Sheehan, 1975) was used to produce statewide coal quality maps on line printers. These were manually converted by a draftsman to mylar maps. In the late 1980s, in cooperation with the U.S. Geological Survey (USGS) Branch of Coal Geology, coal resource studies were completed using PACER for database management and GARNET for graphics and analysis. These were software programs designed to run on Prime minicomputers (Loud, 1988) and later ported to Sun workstations (Loud, Blake, and Fedorko, 1990). Although these were highly specialized software programs designed to classify coal resources, they clearly fit the definition of a geographic information system. The analytical functions of GARNET were later performed with the Geographic Resources Analysis Support System (GRASS) produced at that time by the Army Corps of Engineers (Loud, 1999).

By the early 1990s, several computer platforms were capable of running graphics-intensive two-dimensional GIS, and a number of commercial systems advertising diverse capabilities became available. The next obvious step seemed to be three dimensions, and discussions of exotic voxel and octree three-dimensional data models proliferated among geographers.

Three-Dimensional Problems

Several issues kept WVGES from immediately embracing the concept of producing three-dimensional geologic maps. The software and hardware supporting three-dimensional GIS was quite expensive. Although we had a large amount of data accumulated since the agency was formed in 1897, much digital data development had to take place before it was in a form to be used in even a two-dimensional GIS. Most geologists visualize three-dimensional relationships directly without the aid of computers or software, and expensive three-dimensional software and requisite hardware were a hard sell to management that has quite limited discretionary funds. Finally, most of the work of State geological surveys is regional in nature, and portraying three-dimensional representation requires extreme vertical exaggerations that can visually distort geologic relationships.

Processing Raw Data

In 1995, a controversy about the methods used by the West Virginia Division of Tax and Revenue to appraise mineral resources resulted in a legal settlement that involved revamping the appraisal system by developing GIS models of those resources. Although the actual process is more complicated, in essence those models were to be used to generate tax bills. This change resulted in a cooperative program between WVGES, the West Virginia Division of Tax and Revenue, and West Virginia University to collect raw data and to develop models, programming, and procedures for taxpayers to correct errors. Although some raw data are proprietary and must be held confidential, the models used for taxation must be public record and open to examination. After 14 years of consistent model development, we have a large, growing body of high-quality GIS information about West Virginia's mineral resources.

Geologic Mapping

Several years ago, we realized that this information can be processed to produce geologic maps. The procedures we use are detailed in our DMT'08 poster session entitled "Creating Geologic Maps for the Appalachian Plateau in a GIS Environment"; this is described elsewhere in these Proceedings. These procedures are effective, in part, because many rock unit contacts are stratigraphically at or near economically important coal beds. This means that the structure of major coal beds provides a three-dimensional framework. Because stratigraphic intervals vary consistently in the region and in this part of the geologic section, we are able to interpolate or extrapolate other horizons and to intersect all relevant horizons with digital elevation models in order to define outcrops. The end results are digital outcrops and contour maps of one or more structural horizons. After field checking and correcting errors and inconsistencies, these are used to construct a conventional geologic map. In the process, several additional intermediate data sets are produced, notably grids representing all important horizons. To date, these have been archived, but we have begun to realize that these data, if properly packaged, have other uses, and we are experimenting with how to best produce from these archived files a three-dimensional geologic map.

An Early Experiment

One experiment involved a request for assistance from a local golf course. The pond they use as a source of water for irrigation was leaking. The reason for the leak was that their pond was less than 50 feet above an old underground coal mine in the Pittsburgh coal. At this location the entire interval above the mine appears to be composed of the upper Pittsburgh sandstone of Hennen and Reger (1913). This sandstone unit is cross-bedded and has an unconformable basal contact. This unit is subject to failure along large joint sets, resulting in blocks of overlying rock subsiding into the old mine workings when coal pillars are crushed as a result of age and stress. The greenskeeper at the golf course determined by dye tracing that water was draining from one area of the lake bottom, and had already ordered a large quantity of bentonite to plug the hole. He was concerned about the fate of the water after it leaked from the pond; he had expected the water to emerge from mine entries at a nearby outcrop to the south of the pond and was puzzled when it did not appear. After examining the structure of the coal bed in this area, we explained to him that this outcrop was up-dip from the lake and that the groundwater was flowing to the north, in the down-dip direction. The presence of springs and seeps on the exposed hillside to the north of the golf course were verified in the field. However, the greenskeeper remained skeptical.

After this experience, we began looking at the data that we had accumulated and archived while completing the geologic map of the quadrangle where the golf course was located. We realized that this material could be used fairly efficiently to produce a visualization that would help to explain the situation. The result is Figure 1, which was produced with NVIZ, a part of the GRASS version 6.2 GIS package (GRASS Development Team, 2007). A high resolution digital orthophoto quarter-quad (DOQQ) is draped over a 1/9 arc-second digital elevation model (DEM) to form the portrayal of land surface. The lower surface is based on a grid of the structure of the base of the Pittsburgh coal, which was mined beneath this area. For clarity, this surface has been lowered significantly below the land surface. Elevation information is portrayed by color: red areas are the highest, yellows are intermediate, and blues are the lowest elevations. This illustration makes it easy to see that, in general, any water leaking downward through fractures in the lake bottom would flow into old mine workings, and from there would follow the north-trending dip of the coal and overlying sandstone unit, emerging at the outcrop in a valley on the north side of the golf course. This illustration is the most photogenic result from several experiments that applied open source or commonly available three-dimensional rendering software to the archived GIS data from our more recent geologic mapping projects.

Proposed Elements of a Three-Dimensional Geologic Map

In our preliminary testing, we have found the following set of items useful for three-dimensional GIS applications in the Appalachian Plateau region. They are in two categories: base layers and geologic elements.

Base layers:

- Orthorectified imagery
- Digital Elevation Model
- Hypsography
- Hydrography
- Infrastructure lines (roads, power lines, etc.)
- Cultural points (towns and other points of interest).

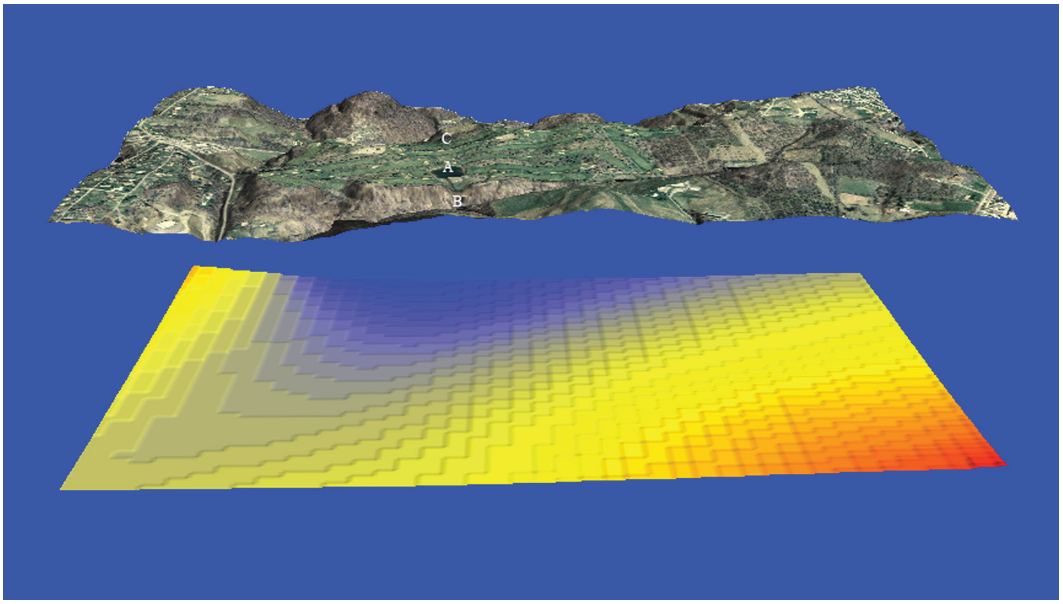


Figure 1. A visualization developed to explain direction of water flow from a leak in the bottom of the golf course lake (A) through old mine workings. North is to top of diagram. The golf course is at the center of the map area, the lake is marked "A," and the updip outcrop is marked "B." The lower surface is based on a grid of the structure of the base of the Pittsburgh coal. For clarity, this surface has been lowered significantly below the land surface. Elevation information is portrayed by color: red areas are the highest, yellows are intermediate, and blues are the lowest elevations. This illustration makes it easy to see that, in general, any water leaking downward through fractures in the lake bottom would flow into old mine workings and then flow northward and emerge from the downdip outcrop "C" in a valley on the north side of the golf course.

Geologic elements:

- Grids representing elevation of all important horizons occurring between land surface and sea level or the base of known geology
- Volume renderings of relevant rock units, if available
- Two-dimensional elements of geologic maps
- Stratigraphic information to fill gaps in the rock record
- Deep subsurface information, if available

The base layers commonly are available for the region. The most important geologic elements are grids of critical horizons. These critical horizons, in particular, are the bases of coal seams and certain other useful marker horizons such as fossiliferous limestone and shale units. Some of these serve as rock unit boundaries in the Appalachian Plateau and others are useful in understanding the stratigraphy. The two-dimensional elements of geologic maps include structure contours generated by contouring grids of selected geologic units and, possibly, fold axes where appropriate. Stratigraphic information includes measured sections, representative core logs, and generalized stratigraphic sections. Deep subsurface information includes various well logs, particularly those from oil or gas wells and other deep borings.

Other Significant Rock Units

In recent years, we have mapped several quadrangles in the Appalachian Plateau and have extensive experience in mapping and in responding to requests for information and assistance. Our goal in the current mapping work is to map traditional formations and groups as well as the most important marker beds, although we realize that there would be value in mapping other rock units where adequate data are available to do so. Notably, some of the laterally extensive sandstone and limestone units that have hydrogeologic, cultural, or environmental significance are important to map.

In the areas we have mapped in the northern part of the Appalachian Basin of West Virginia, the most significant of these units are the Waynesburg sandstone, the Grafton sandstone, and possibly the Sewickley and Benwood limestones (all of Hennen and Reger, 1913). The Waynesburg sandstone appears to be composed of sands deposited in one or more stream channels that meandered and "jumped" to create new channels, resulting in a sandstone of nearly continuous extent

(Donaldson and others, 1979). It is a subtle, but very recognizable unit in north-central West Virginia, where it forms gently rolling upland valleys that have traditionally been farmed (Figure 2). These valleys typically end at waterfalls formed in the Waynesburg sandstone (Figure 3). Detailed mapping of this unit would be time consuming, and it is beyond the scope of our 1-year STATEMAP quadrangle mapping projects.

Figure 2. Gently sloping upland farmland underlain by the Waynesburg sandstone of Hennen and Reger (1913) in north-central West Virginia.

Figure 3. A small waterfall has formed by an outcrop of the Waynesburg sandstone of Hennen and Reger (1913). The underlying Waynesburg coal has been mined locally for house coal at this location.

The Grafton sandstone of Hennen and Reger (1913) is present in both our north-central and northern panhandle mapping areas. In West Virginia's northern panhandle area, this unit appears to be composed of the sands deposited in one or more stream channels (Figure 4), whereas in north-central West Virginia it represents the prodelta of the Grafton fluvial system, which is in places cut by delta plain channels (Figure 5) (G.H. McColloch, unpub. data, 1975). The deposits of the northern panhandle are probably younger than those in north-central West Virginia because the Grafton represents a prograding shallow water delta system with downcutting of younger channels into older deposits. In both the Wheeling and Morgantown areas, it has formed rock terraces that had a significant role in controlling early human settlement patterns. Later, the Grafton rock terraces formed the flat areas where factories and residential neighborhoods were located.

Figure 4. Outcrop of the Grafton sandstone of Hennen and Reger (1913) in Brooke County in West Virginia's northern panhandle. The gap in this narrow ridge was created when one of two of the oldest tunnels on the western slope of the Appalachians was daylighted.

The Sewickley and Benwood limestones of Hennen and Reger (1913) are of interest because they form small caves (Garton and Garton, 1976) in a region that is otherwise devoid of karst features, and because they provide a local source of low quality aggregate. These karst features are not as significant as karst features in the thicker, purer carbonate units elsewhere in the Appalachians, but they have caused engineering problems. These units also provide a local source of impure limestone.

Figure 5. The Grafton sandstone of Hennen and Reger (1913) is present in the upper part of this road cut located in the Morgantown area. The dark zone (A) is the Harlem coal. The overlying Ames shale and limestone of Hennen and Reger (1913) (B) occurs between the Harlem coal and the Grafton sandstone (C). The Grafton at this location is sedimentologically complex, forming in several environments characteristic of a shallow water delta system and including rocks representing prodelta, lower delta channel deposits, and a coal formed in the abandoned channel (G.H. McColloch, unpub. data, 1975).

References

Donaldson, Alan, Drennan, Larry, Hamilton, Wallace, Linger, Daniel, Kimutis, Robert, King, Hobart, Moyer, Carol, Renton, John, and Zadi, Mohammad, 1979, Geologic factors affecting the thickness of Upper Pennsylvanian coals of the Dunkard Basin, *in* Carboniferous Coal Short Course and Guidebook: Morgantown, WV, Department of Geology and Geography, West Virginia University, 300 p.

Dougenik, J.A., and Sheehan, D.E., 1975, Symap User's Reference Manual: Cambridge, MA, Harvard University Graduate School of Design, Laboratory for Graphics and Spatial Analysis, 198 p.

Hennen, R.V., and Reger, D.B., 1913, Marion, Monongalia, and Taylor Counties: West Virginia Geological Survey, County Report Series, 844 p.

Garton, Ray, and Garton, M.E., 1976, Caves of north central West Virginia: West Virginia Speleological Survey, Bulletin 5, 108 p.

GRASS Development Team, 2007, GRASS 6.2 Users Manual: ITC-irst, Trento, Italy, available at *http://grass.osgeo.org/grass62/manuals/html62_user/*.

Loud, E.I., 1988, The coal availability study in West Virginia: Beckley 7.5' Quadrangle, Raleigh County, WV: West Virginia Geological and Economic Survey, Open File Report OF9004, 43 p.

Loud, E.I., 1999, The coal availability study in West Virginia: Tables of results for Crumpler, Man, Rivesville, Glover Gap, and Thornton 7.5' Quadrangles, WV: West Virginia Geological and Economic Survey, Open File Report OF9901, 131 p.

Loud, E.I., Blake, B.M., and Fedorko, Nick, 1990, The coal availability study in West Virginia: War 7.5' Quadrangle, McDowell County, WV: West Virginia Geological and Economic Survey, Open File Report OF9005, 70 p.

Online Manuscript Review Process: Using Adobe Acrobat Review and Comment Features

By Richard T. Hill

Indiana Geological Survey
611 North Walnut Grove Ave.
Bloomington, IN 47405
Telephone: (812) 855-9583
Fax: (812) 855-2862
email: *hill2@indiana.edu*

Introduction

The Indiana Geological Survey (IGS) has added an online review component to its manuscript review policy and procedures. IGS staff can now submit documents to either the new online review process or to the traditional on-paper review paper. The IGS online peer review procedure makes use of a Shared Review application in Adobe Acrobat Professional, Version 8 and higher. Document types that can be reviewed online include manuscripts, abstracts, proposals, maps, metadata, posters, brochures, illustrations, spreadsheets, database tables, graphics, scanned images, Web pages, or any material that can be converted into a Portable Document Format (PDF) file.

The Indiana Geological Survey Peer Review Process

The IGS peer review process is designed to assist authors by improving the content of their work, finding errors, and ensuring that documents conform to IGS guidelines for both internal and external publications. The review process is essentially the same for both online and paper review. Documents are checked by technical, geologic, editorial, and administrative personnel, who provide constructive feedback and comments to authors.

After preparing a document, the author first sends it to the immediate supervisor (the Section Head) for preliminary review. Upon the supervisor's approval, the document is forwarded to the IGS Review Coordinator who selects technical, geologic, and other reviewers. Reviewers make their comments on the paper document. The reviewed copy is then returned to the author for revision. The author assesses the feedback and comments and makes the appropriate changes to the document. The author also responds in writing to each reviewer comment that he or she rejects. After the author makes the appropriate changes, the IGS Review Coordinator checks the document to make certain review comments were accepted or acknowledged.

The document is then forwarded to the editor, who edits the manuscript and returns it to the author. Again, the author assesses the comments and makes the appropriate changes and modifications. It then is forwarded to the Director for approval for final production.

LGS Online Review

To submit their documents to the IGS Online Review, staff members convert their paper or digital documents to a PDF file. The IGS Review Coordinator adds an electronic routing sheet to this file and processes it using the Shared Review application in the Review and Comments feature of Adobe Acrobat Professional (Figure 1). To begin a review, the reviewer follows these steps:

1. Open Adobe Acrobat Professional, select *Review and Comments* feature, and select *Start a shared review*.
2. Select the PDF file to be reviewed and select or create a shared network folder where the application saves a copy of the PDF file (Figure 2).

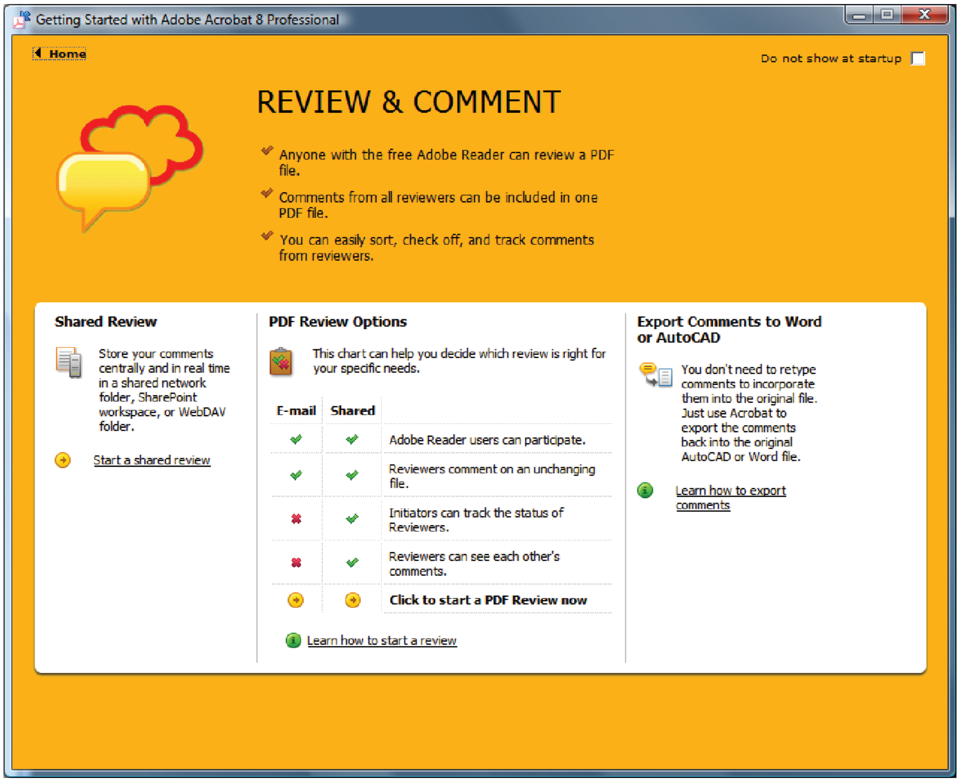


Figure 1. Adobe Acrobat's Review and Comment application.

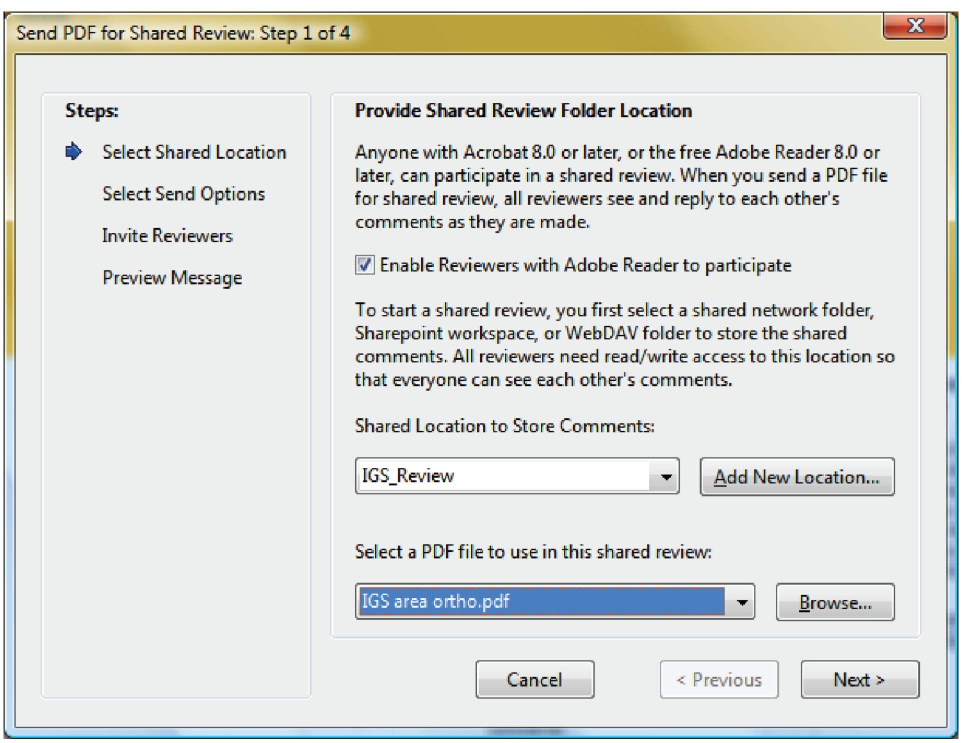


Figure 2. Select a Shared Location to Store the Comments and select the PDF file to review.

a. The IGS Review Coordinator, author, and reviewers must all have read and write privileges to the shared network folder.

b. If any of the Reviewers use the free Adobe Acrobat Reader, Version 8 and above, select the *Enable Reviewers with Adobe Reader to participate* feature.

3. Select the PDF as an attachment or link to send in the e-mail message (Figure 3).

   a. The *Attach PDF to the message and save a copy locally* feature is used by reviewers who do not have access to the shared network folder, namely, reviewers outside the organization. Upon completing the review, the reviewer returns the PDF file, via e-mail, to the IGS Review Coordinator who posts the reviewer's comments to the shared network folder.

   b. The *Send a link to the PDF in the message* feature is used by reviewers with access to the shared network folder. This is the preferred method within the IGS.

4. Enter the reviewer's e-mail addresses into the application (Figure 4).

   a. Optional reviewers may also be entered.

   b. A review deadline may be entered, following the specific format.

   c. The e-mail address book may be activated, allowing the Review Coordinator to select the reviewers.

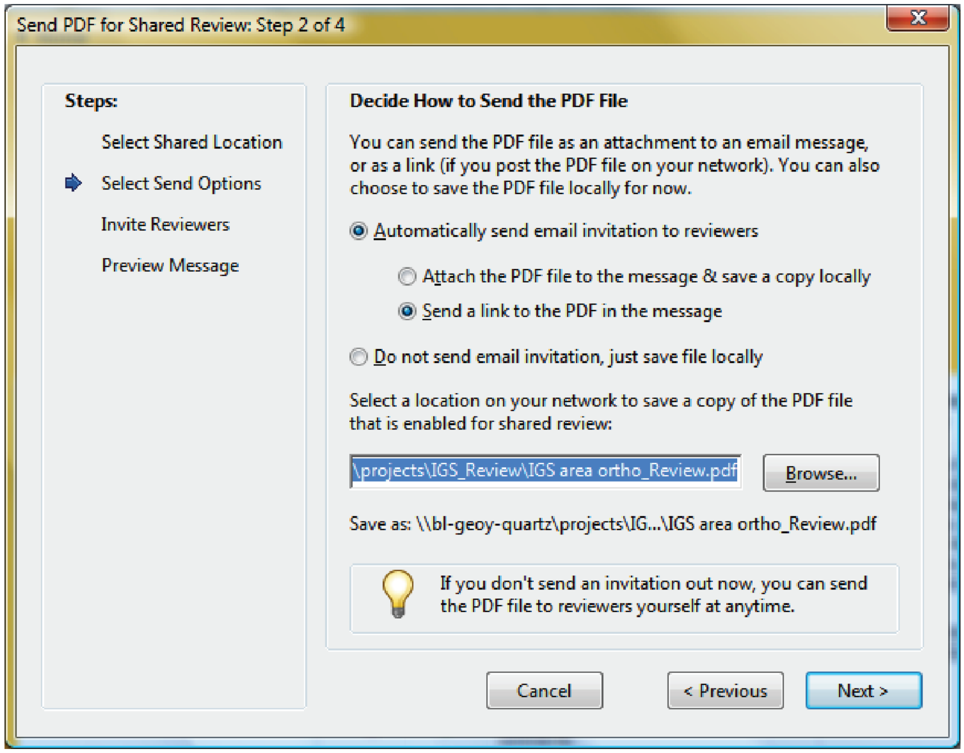


Figure 3. Send the PDF as an attachment or link in an e-mail message.

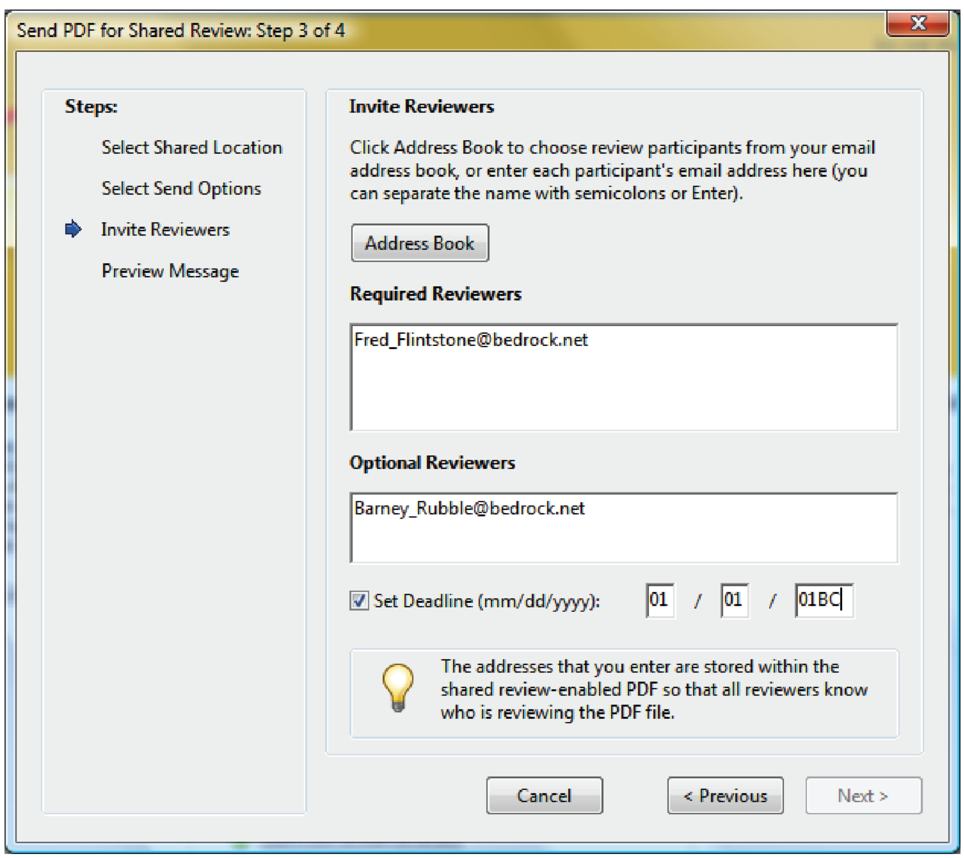


Figure 4. Invite reviewers and optional reviewers by entering their e-mail addresses; you can use the e-mail address book to enter your selections. A deadline also can be entered.

5. Preview the default e-mail message that will be sent to the reviewers (Figure 5). The message can be modified as necessary.

The online review is conducted simultaneously, whereby reviewers are sent an e-mail message containing either an attached PDF file, or a link pointing to the PDF file stored on a shared network folder, to be reviewed. As reviewers mark up the document and publish their comments using Acrobat's Review and Comment feature, the comments are stored in the shared network folder for the author, editor, IGS Review Coordinator, and other reviewers to view and examine. The author may begin making changes to the document before the last review has been completed, if they choose. The Review Coordinator is notified by the Adobe's Review Tracker alerts whenever any new comments have been made, and, thus, is able to track the review progress.

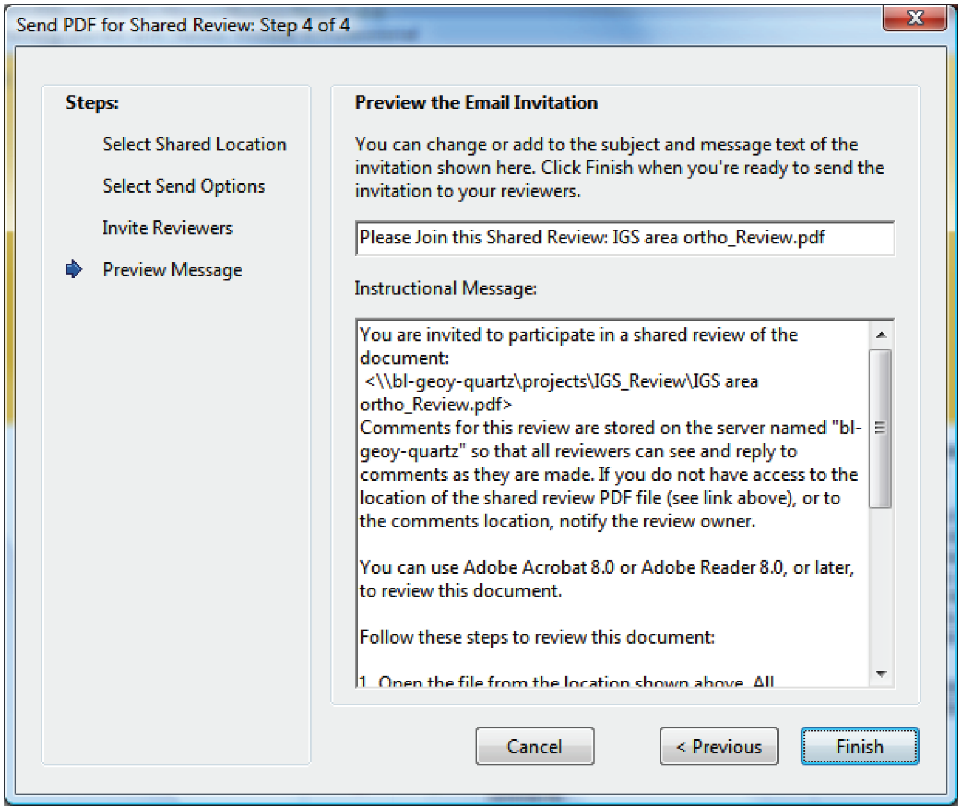


Figure 5. Preview the e-mail invitation and modify as necessary.

Review Comments and Markups

Reviewers receive an e-mail invitation to review an online document (Figure 6). The message contains either the attached PDF file or a link to the PDF file. Opening the PDF file in Abode Acrobat will also launch the Comment and Markup tools. These tools, such as the Sticky Note, Text Edits, Callout, and Drawing tools, are

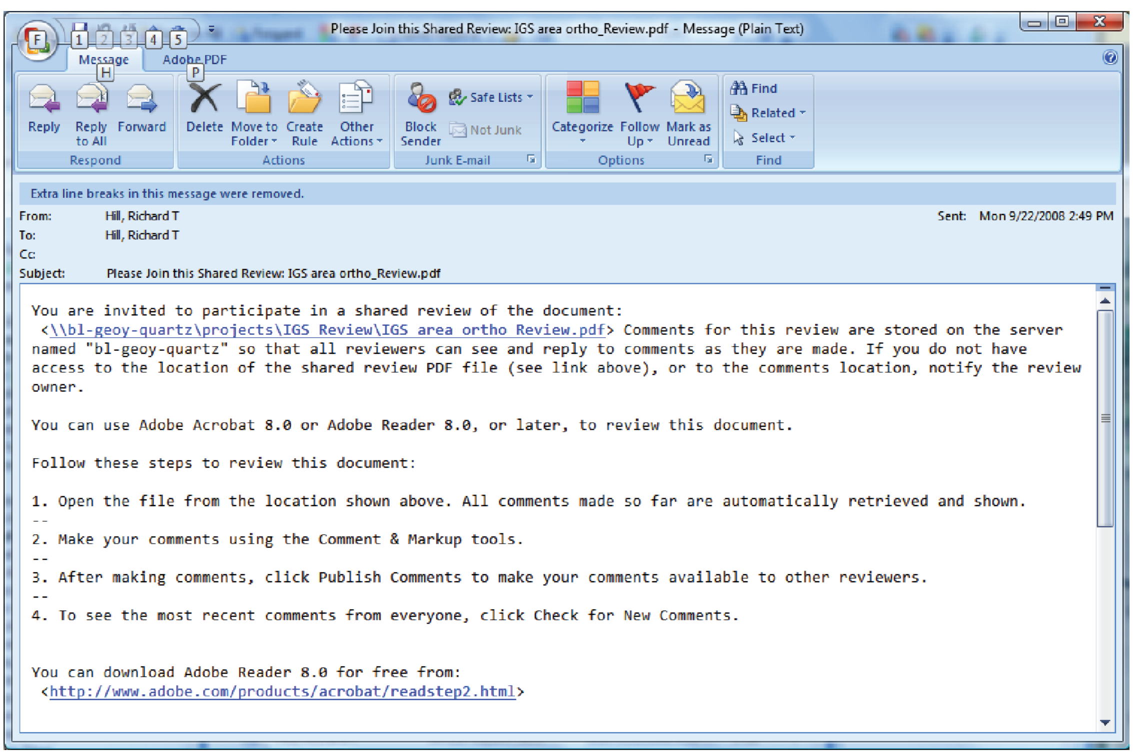


Figure 6. Sample of e-mail message reviewers receive.

used to add comments and suggested edits to the document. The Show Comments List tool opens a window at the bottom of the PDF allowing reviewers to view all the comments and authors to respond to each comment (Figures 7 and 8).

For author corrections of reviewed documents containing text, Adobe Acrobat Professional provides an Export Comments to Word function from within the Review and Comment toolbar. This feature converts the comments to the Microsoft Word Track Changes function, where authors can easily make the necessary updates. The updated Word document can easily be converted back to PDF if necessary.

Author Assessment and Feedback

The author assesses the feedback and comments and makes the appropriate changes to the document. Additionally the author writes a response to each major review comment if he or she chooses not to make the suggested change. This task is easily accomplished using the Show Comments List tool. Each comment is displayed in the list. Selecting one comment will highlight it in the review document and allows the author to reply, sort, or set its status.

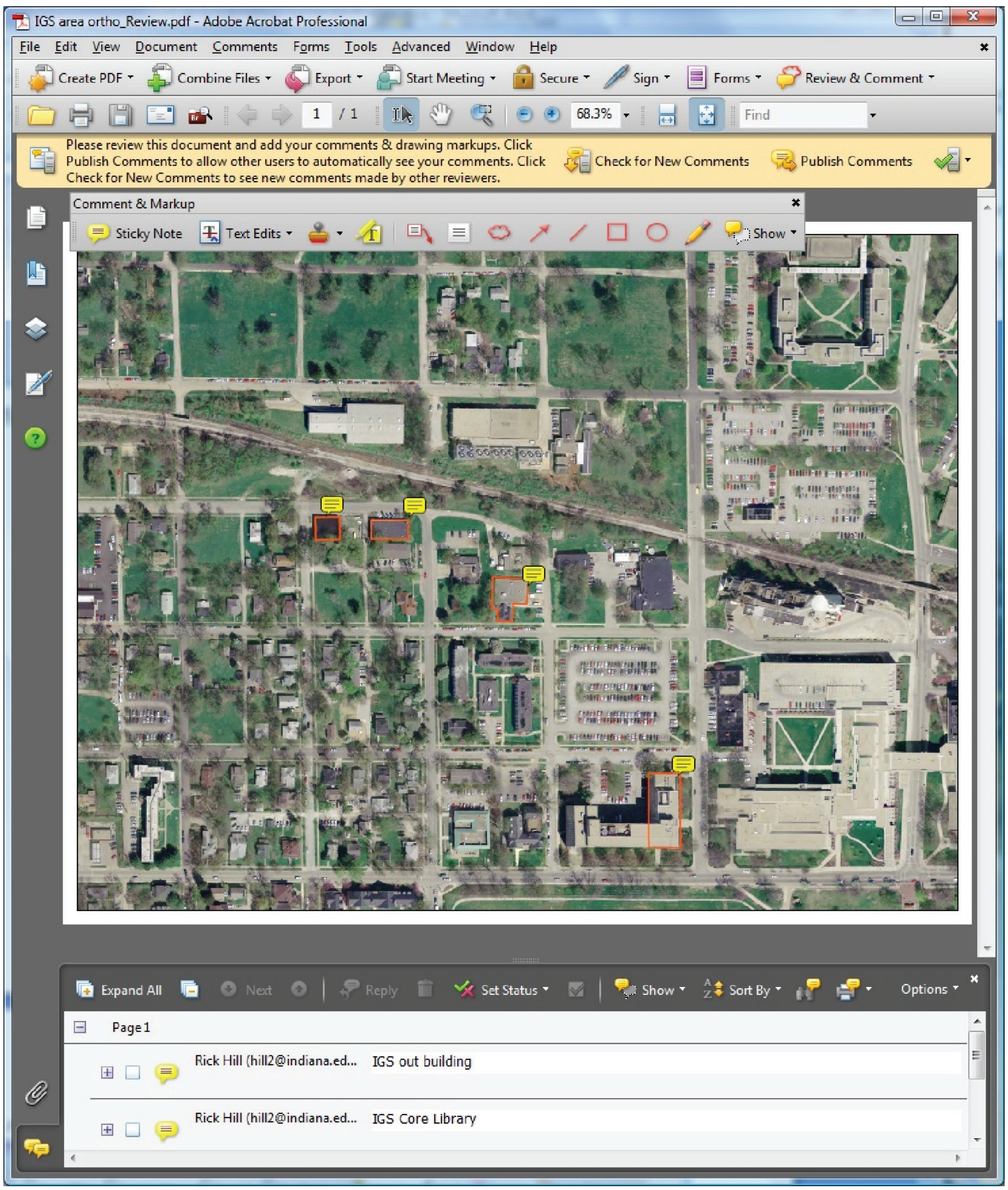


Figure 7. When reviewers receive the document, they click the Check for New Comments button to display the Comment and Markup toolbar.

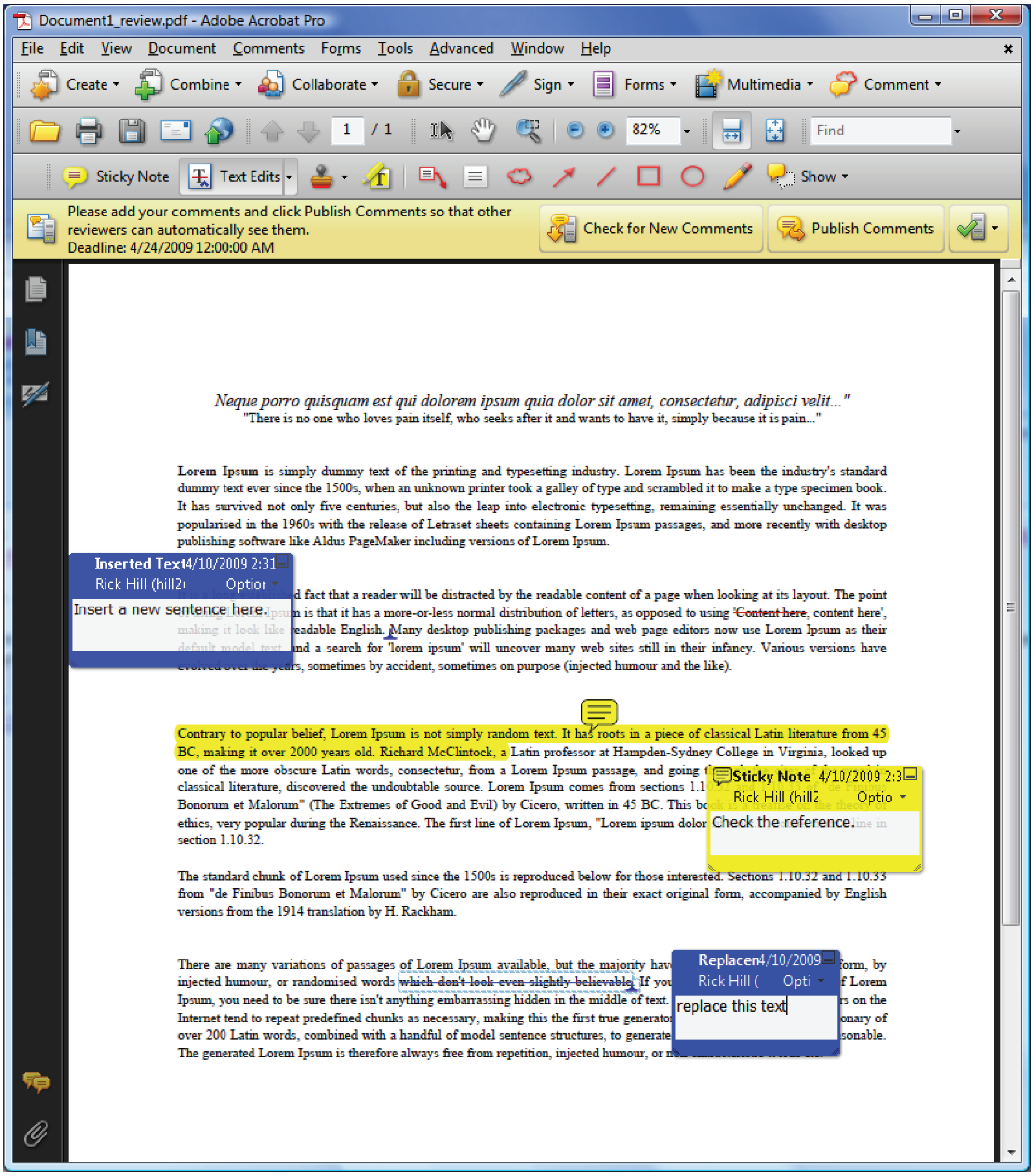


Figure 8. This document shows examples of inserting, replacing, and deleting text and highlighting text to make comments.

Comments and Feedback From IGS Staff Regarding the Online Review Process

- Experience has shown that the online review takes much less time to route a document through the review process compared with the traditional on-paper review. The quality of the online review is the same as the traditional on-paper review.
- A wide range of document types can be more easily reviewed using the online review process compared with the on-paper review process (namely, manuscripts, abstracts, proposals, maps, metadata, posters, brochures, illustrations, spreadsheets, database tables, graphics, scanned images, and Web pages).
- Some staff members prefer the traditional on-paper review process. Reading long manuscripts on a computer screen is not for everyone and may cause eye fatigue.

- The ability to review many types of documents in a single PDF file is a key benefit.
- The learning curve for the online review process is short. Many staff members have reported that they were reasonably comfortable with the online review process after completing several reviews.
- For Web page reviews, the Review Coordinator should include both a link to the PDF version of the Web page, and a link to the actual Web page on the development Web server. This will allow reviewers to view the Web content with all features enabled. Some Web content does not always translate well to the PDF format.

For More Information

In Adobe Acrobat Professional you can learn more about the Review and Comment features by clicking on *Getting Started with Adobe Acrobat Professional* under the Help menu, then clicking on the *Review and Comment* button.

Bringing Geological Mapping into the Digital Era—A Finnish Case

By Niina Ahtonen, Hannu Idman, Esa Kauniskangas, Jarmo Kohonen, Jyrki Kokkonen, Jouni Luukas, Jukka-Pekka Palmu, and Jouni Vuollo

Geological Survey of Finland
P.O. Box 96, FI-02151, Espoo, Finland
Telephone: (+358) 2055030
Fax: (+358) 2055012
email: *firstname.surname@gtk.fi*

Introduction

The Geological Survey of Finland (GTK), like most long-established geological surveys, is in the process of renewing its mapping strategies. The revolution in information technology, pressures for greater responsiveness to customer groups, and the push for greater organizational efficiency are the main drivers behind this process. Web-based approaches also increase the importance of being able to query and exchange geoscientific information internationally.

The largest issues to be tackled in the renewal process relate to data models and architecture, data capture and acquisition, as well as dissemination and delivery of information. The process occupies considerable resources and demands a wide variety of skills. To date, GTK has expended some 200 man-years just on digitizing legacy data. Moreover, even with careful planning, the process has not been straightforward. The original plan of centralized storage based on an ESRI Geodatabase data structure (Oracle-ArcSDE platform) has been revised. We now divide the databases into spatial (Oracle-ArcSDE) and aspatial parts (e.g. geological unit register with attribute data in relational databases).

The present focus is on careful analyses of work flows to modernize our mapping processes, finalizing national data models for Precambrian and Quaternary geology, and reworking the data structures accordingly. Designing seamless map databases for the entire country and map products at scales of 1:1 million and 1:200,000 are underway.

Moving from Paper to Digital

Over the past 10 years, GTK has digitized all fundamental datasets (surficial and bedrock geology data, exploration, aggregate resources, peat resources, etc.) and transferred existing digital data into the new databases. Our databases currently contain a vast amount of observation points, vector/raster maps, and exploration datasets that include claim reports, drilling sites, and report maps.

By organizing these data according to in-house standards, we are in a position to provide extensive web-based services such as maps, index-based services from different kinds of point and polygon data, and archived reports. The quick-and-dirty approach to digitization has preserved rich bodies of geological information that might otherwise be lost, but it has hardly brought us closer to our ultimate goal of services based on fully harmonized datasets. However, a lot of legacy information is still in its original formats awaiting further revision, digitization, and harmonization. The planning of the future operations needs balancing of partly conflicting aspects: the ultimate goal of completely harmonized datasets seems too remote, whereas a simple bulk digitizing of materials without any revision of the content does not enable high-quality information services.

GTK´s vision of being a national geoinformation centre necessitates finding ways to make numeric datasets accessible, relevant, and easy to use. Interoperability in Europe (the EU’s INSPIRE directive; *http://www.inspire-geoportal.eu/*)

and global collaboration (OneGeology; *http://onegeology.org/*) requires normative conceptual data models, classification systems, and common geological terminology. For this purpose, GTK is beginning a transition to harmonized databases, governed largely by the recommendations of the INSPIRE directive and technical specifications in the emerging data-transfer standard GeoSciML (*http://www.geosciml.org/*). International networking, e.g. with the IUGS-CGI [*http://www.cgi-iugs.org/*], NADM [*http://nadm-geo.org/*], and GeoSciML teams, plays a significant role in the harmonization process.

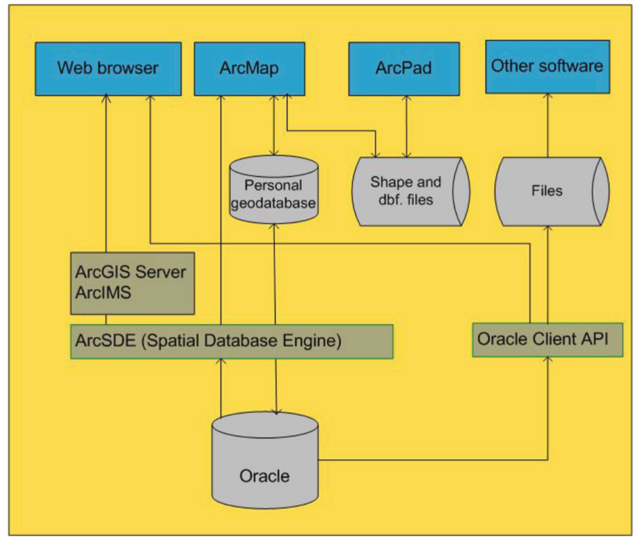


Figure 1. GTK´s data architecture is based on a centralized Oracle database and ESRI's ArcGIS software family. ArcMap and ArcGIS server (running on Web browser) are the main client software products. Large georeferenced raster images are served with IWS-software (ERDAS ER Mapper). Web Map Service (WMS) and Web Feature Service (WFS) interfaces are also available.

Architecture and Databases

GTK's original plan, dating back a decade, featured centralized storage based entirely on an ESRI Geodatabase data structure (Oracle-ArcSDE platform). In recent years, the architecture was divided into spatial (Oracle-ArcSDE) and aspatial parts (Oracle, but not SDE). The present situation is illustrated in Figures 1 and 2.

The motivation for a divided architecture came from the plan of GeoScience Victoria of Australia (GSA) for their map database solution. The primary plan of GSA was to store everything in an ESRI Geodatabase, but after their evaluation process, a combination of RDBMS and GIS technology was selected (see in detail Simons and others, 2005).

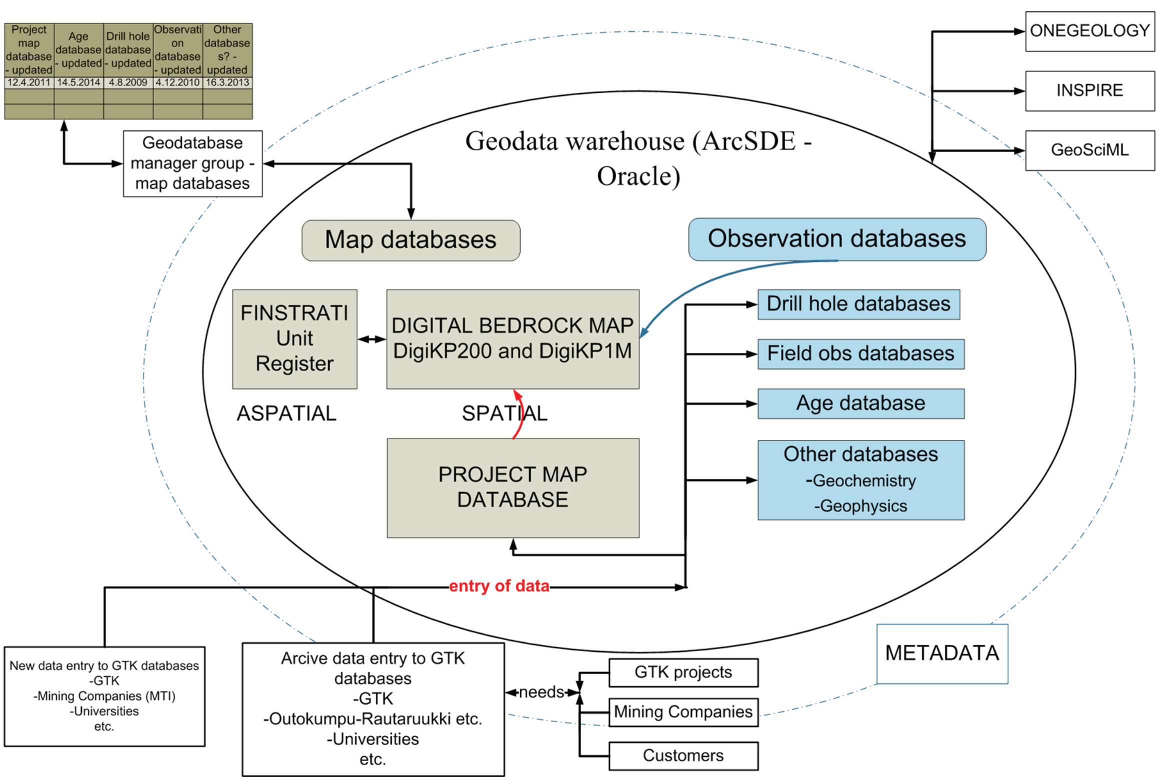


Figure 2. GTK's database structure for bedrock data. New data and maps – from archives and field – will be stored in observation and map databases that are used to design harmonized seamless geology map databases at 1:200,000 and 1:1 million scales linked to the aspatial unit register.

Also, a "divided approach" was strongly supported by the decision of GTK to create seamless countrywide map databases of our Precambrian bedrock at 1:1 million and 1:200,000 scales (DigiBr 1M and DigiBr 200), on a geologic map unit basis. This meant jettisoning the purely lithological approach of the original plan. Guidelines and procedures for naming Precambrian units in Finland were drawn up largely following recommendations in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005). These guidelines have been used to design the geological unit register consisting of lithostratigraphic, lithodemic, and tectonostratigraphic units with attribute data in relational databases. This is illustrated in Figure 2.

Field Data Capture and Acquisition

Field data capture is important for GTK. Because data models used by GTK are complicated, GTK has focused software programming strongly on attribute editor development. Attribute editors are programmed on top of ArcGIS. In surficial deposit mapping and bedrock mapping, field data capture is done with portable tablet PCs (see our DMT poster for details [*http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_Kokkonen.pdf*]). Base maps, geophysical maps, previously made observations, etc., are in digital format and can be manipulated with GIS software in the field. Bedrock and surficial deposit observations are stored using standard ArcMap tools and customized editors.

The database structure is complex. For example, the data model for bedrock observations covers sub-processes such as regional bedrock mapping, exploration, natural stone investigations, and urban geology for construction purposes.

Map Production and Delivery

GTK's Map Production Extension (Figure 3) is an information processing and cartographic editing system for geologic maps and map products. The system is not a data management tool, but rather specialized process software for map production and publishing. It is based on a double-server architecture, whereby end-users with Windows-based tools are connected to Unix-based database services. Product groups and different products are predefined in the system, as are the symbol sets, colors and annotations. Users are administered according to their roles in the process.

Data in the database server are managed by Oracle RDBMS and stored on Oracle-managed disks. ArcSDE connects the Oracle and GIS systems. The customer server architecture allows for sharing of information, centralized information management of controlled work, and processing of optimized information.

All original material is maintained in source databases. The source databases consist of GTK's Oracle – SDE database for geologic information and the National Land Survey's terrain database for base maps. The material from source databases is copied into a map database according to area delimitations of the product.

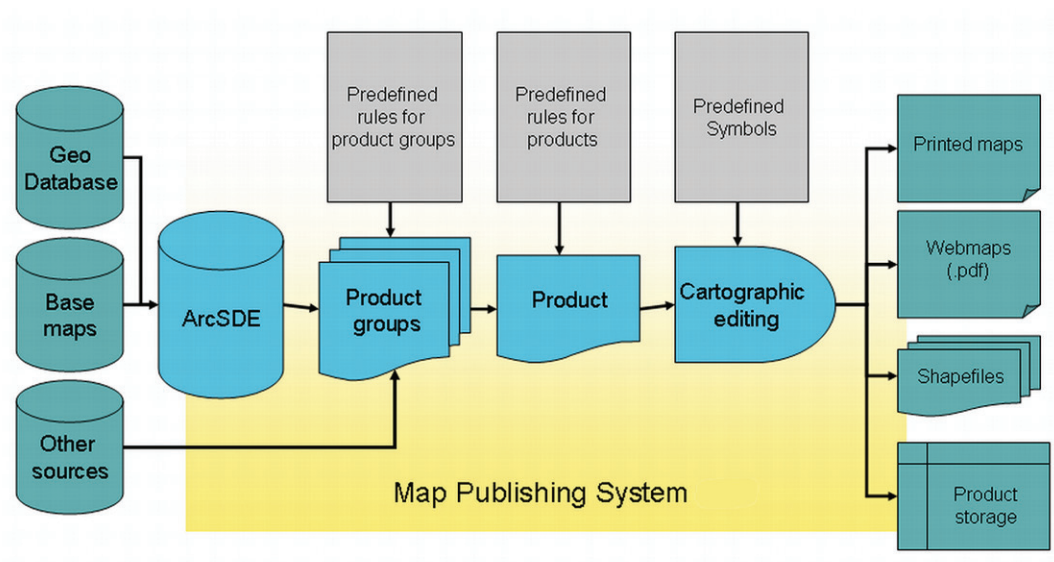


Figure 3. Map production extension used by GTK.

The end products are various size and quality printouts, including Adobe PDF files (.pdf) and ESRI shapefiles (.shp).

Web Publishing

The GTK service model (Figure 4) is a portal, based on an ArcGIS Server 9.x for vector data and an ER Mapper Image Web Server for raster/matrix data. Basemaps are uploaded via a WMS interface developed by the National Land Survey and Karttakone Ltd. Geospatial data used in this service come from GTK's database or other sources.

The service should accommodate standard web browsers (basic users) or GIS software (advanced users). It will also work with Open Geospatial Consortium (OGC) interfaces. The Data Interoperability Extension built into the system allows downloading of data in a variety of formats (e.g. AutoCAD, Mapinfo, ESRI shapefiles). It is also possible to search spatial and areal information. Reports and other documents are readable or downloadable in Adobe PDF. Ordering services for printed documents, maps, and reports are included.

References

North American Commission on Stratigraphic Nomenclature, 2005, North American Stratigraphic Code: AAPG Bulletin, v. 89, No.11, November 2005, p. 1547-1591, available at *http://ngmdb.usgs.gov/Info/NACSN/Code2/code2.html*.

Simons, B., Ritchie, A., Bibby, L., Callaway, G., Welch. S., and Miller, B., 2005, Designing and building an object-relational geoscientific database using the North American Conceptual Geology Map Data Model (NADM-C1) from an Australian perspective: Proceedings of IAMG'05: GIS and Spatial Analysis, v. 2, p. 929-934.

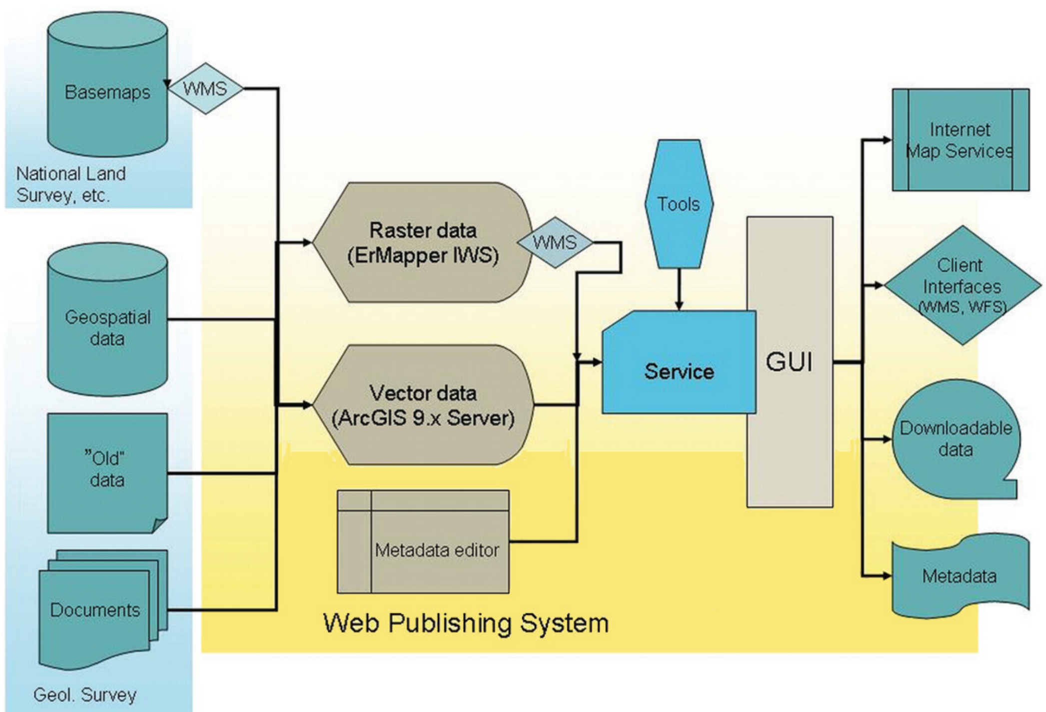


Figure 4. GTK´s Web service model. The Web Publishing System serves as GTK's portal.

Creating a Virtual Geologic Map and Field Trip of the St. George 30′x60′ Quadrangle, Washington County, Utah: An Adventure in Google Earth

By Kent D. Brown, Lance B. Weaver, and Robert F. Biek

Utah Geological Survey
1594 W. North Temple
Salt Lake City, Utah 84116
Telephone: (801) 537-3300
Fax: (801) 537-3400
email: *kentbrown@utah.gov*

Introduction

The concept of a virtual geologic field trip is very attractive to a geologist who wants a more interactive and visual method of telling a geologic story to others, especially non-geologists, than is possible using a traditional paper geologic map. This virtual field trip uses the popular internet virtual globe interface, Google Earth, in combination with a transparent geologic map overlay, photographs, illustrations, and descriptions of selected geologic features, to help users understand the geology of the greater St. George, Utah, area. An overview of the product and the method are shown in the accompanying poster (Figure 1).

Because users of virtual globes naturally want to zoom in to see the landscape in as much detail as possible, we used a high-resolution geologic map as a base on which to build our field trip. We also sought to automate construction of the field trip as much as possible, and found that creating much of the

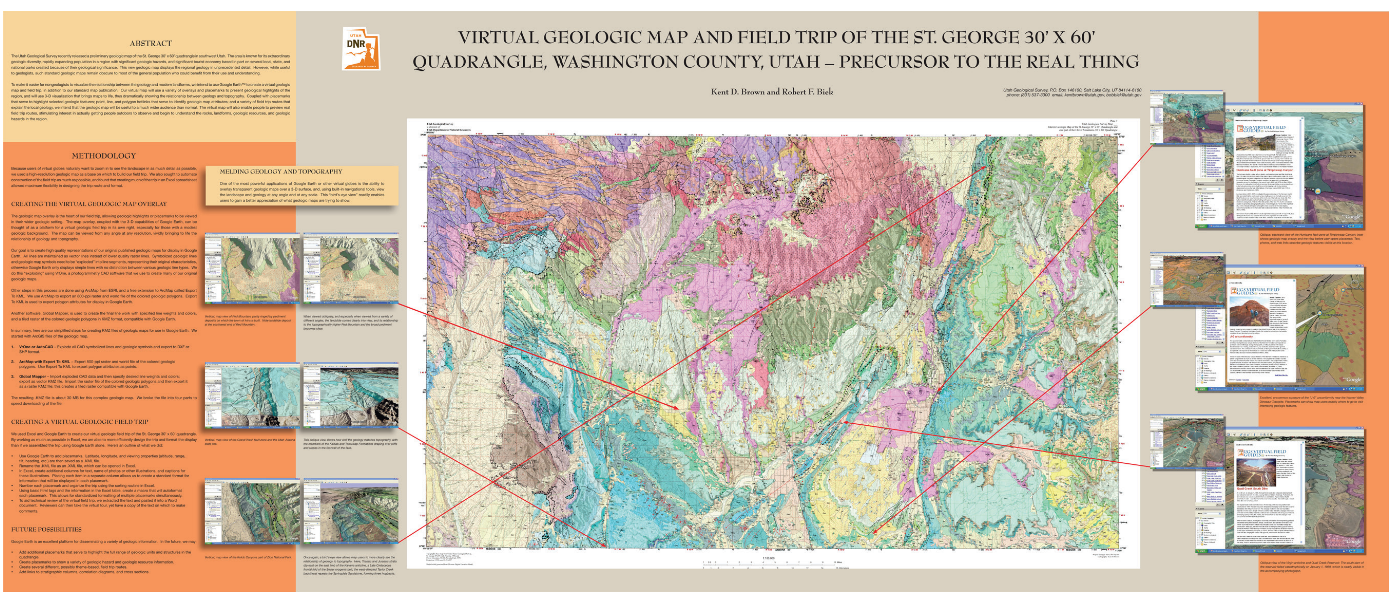


Figure 1. Poster created to show concept and procedure (presented as a poster; see full-resolution image at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_Brown.pdf*.)

trip in an Excel spreadsheet allowed maximum flexibility in designing the trip route and format.

Creating the Virtual Geologic Map Overlay

The geologic map overlay is the heart of our field trip, as it allows geologic highlights and placemarks to be viewed in their wider geologic setting. In Google Earth, the map can be viewed from any angle at any scale, vividly bringing to life the relationship of geology and topography (Figure 2). For those with even a modest geologic background, the map overlay, coupled with the 3-D capabilities of Google Earth, serves as a virtual geologic field trip in its own right, even without adding photographs and descriptions. However, we feel that the viewer's experience and geologic understanding of this virtual map are improved with these added features.

Our goal is to create high quality representations of our original published geologic maps for display in Google Earth, so that all lines are maintained as vector lines instead of lower quality raster lines. The GIS data we use to create these Google Earth maps is in ESRI geodatabase format.

Because Google Earth does not currently support ESRI ArcMap line symbology, (dotted lines, dashes, teeth on thrust faults, etc.) only the line colors and line widths can be exported to Google Earth KML (Keyhole Markup Language) format. Geologic map point symbols (bedding symbols, fault symbols, fold symbols, etc.) and geologic unit polygons with pattern fills are also unsupported. Therefore, to display our geologic maps correctly in Google Earth we find it necessary to "explode" symbolized geologic lines and geologic map symbols into line segments representing their original symbol characteristics. We do this "exploding" using VrOne photogrammetry CAD software from Cardinal Systems, LLC. (Our primary use of VrOne is to create the initial symbolized lines and geologic map symbols for many of our original geologic maps, before the GIS data are created.)

We further process the data using ArcMap v. 9.x from ESRI, and a free user-created extension to ArcMap called Export To KML, which we use to export geologic polygon attributes for display in Google Earth. We also use ArcMap to create a "high-resolution" geo-referenced raster image of the colorful geologic polygons.

Global Mapper, from Global Mapper Software, LLC, is used to create the final line work with specified line weights and colors, and a tiled raster image of the colored geologic polygons in KMZ (a compressed version of KML) format, that are compatible with Google Earth.

In summary, we follow four simplified steps for creating KMZ files of geologic maps for use in Google Earth:

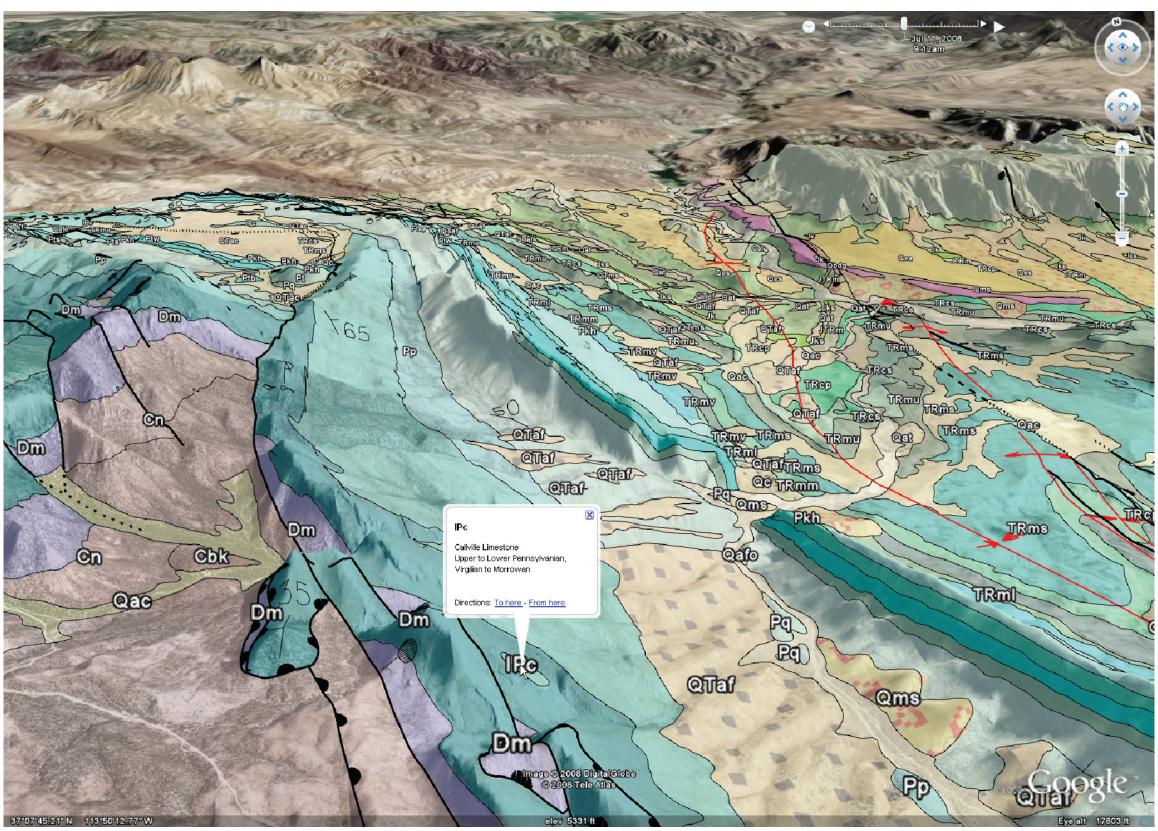


Figure 2. Example of a virtual geologic map overlay in Google Earth, showing geologic unit information in a "balloon."

1. **VrOne or AutoCAD** – Initially, all geologic lines and map symbols are created in a CAD environment. We explode all CAD symbolized lines and geologic symbols and export them to DXF or SHP format.
2. **ArcMap with Export To KML** – We export an 800-ppi raster image (BMP or TIF) and world file of the colored geologic map polygons. Exporting this raster image from the ArcMap view is currently the only way we can preserve the cartographic patterns that are used in some of the geologic unit colors. Then we use the Export To KML extension to export geologic unit symbols from the polygons. This gives us a KML file of points, along with attributes for unit name and geologic age that are used in Google Earth as clickable points that display the attributes of the geologic units in a pop-up information balloon.
3. **Global Mapper** – We import the exploded CAD data, specify desired line weights and colors for the features, and then export them once again as a vector KML file. Then we import the raster image of the colored geologic polygons and then export it back out as a raster KMZ file; this creates a more efficient tiled raster image that is compatible with Google Earth.
4. **Google Earth** – We open the three files created in the above sequence; that is, the raster KMZ file of the geologic unit colors, the KML file of the vector lines, and the KML file of the geologic unit symbols. Then we export them all together as one KMZ file.

The resulting KMZ file for this complex 30'x60' geologic map is about 30 MB. Therefore, we divided the map into four parts to speed downloading of the files and to increase the display performance in Google Earth. We recommend that the geologic unit colors of these maps be made about 50% transparent in Google Earth so the terrain imagery is visible through the geology.

Creating the Virtual Geologic Field Trip Stops

To further enhance the experience of the virtual geologic map and to partially recreate an actual geologic map field trip, we created numerous virtual field trip stops as Google Earth placemarks. The placemarks activate informational balloons that include photographs of key geologic features, illustrations, and descriptive text about each stop, in addition to links to larger versions of the photos and to the Utah Geological Survey website. The result is a sequence of placemarks that are "played" in Google Earth as if they are a video, automatically flying over the terrain and zooming in at each placemark to display the balloon information (Figure 3).

We created the Virtual Geologic Field Trip of the St. George 30' x 60' quadrangle using Microsoft Word, Microsoft Excel, and Google Earth. By working as much as possible in Excel, we were able to more efficiently design the field

Figure 3. A virtual geologic field trip stop in Google Earth, showing an information balloon that explains gravity-slide blocks.

trip and to format the display than if we had assembled the field trip using Google Earth alone. We also created an Excel spreadsheet with a UGS-specific macro application (Excel-to-KML.xls, which is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_Brown.zip*) that we use as a template for organizing and streamlining the creation of these virtual field trips. You can use this template to create a KML file for your field trip, by simply pasting your data on top of the examples in the "example-data" sheet and then running the macro application.

This project has three principal aspects: writing the field trip stop descriptions using Microsoft Word; creating the field trip placemarks in Google Earth, and setting the viewing angle, azimuth, distance to subject, and picture link locations; and combining the field trip placemark names and stop descriptions with the geographic coordinate information from Google Earth, in order to build the KML-based field trip.

Here's how we do it:

1. Create the field trip stop descriptions in Microsoft Word.
2. Use Google Earth to add placemarks to appropriate geographic locations. You could use the "add placemark" feature of Google Earth to do the whole process of creating the KML, but that would require copying and pasting each field trip title, description, image, and HTML formatting into the placemark boxes individually. To save time, create only the placemark names and locations, and, optionally, altitude, range, tilt, and heading in Google Earth. After creating your virtual trip placemarks, simply save them as a KML file, not a KMZ file. KMZ files are compressed and you cannot edit them in Excel, which we do in step 4.
3. Rename your placemarks KML file extension to **.xml** (Note: viewable file extensions must be enabled in Windows Explorer to do this). This XML file can now be opened in Excel versions 2003 and later (Excel 2007 does this best) and will be automatically parsed into a tabular format. Google Earth tends to add a large amount of extraneous style information, but you only need fields such as latitude, longitude, altitude, range, tilt, heading, etc. Search through the XML file in Excel to find the data that match the pattern shown in the "**example-data**" sheet of the **Excel-to-KML.xls** spreadsheet. Select the ranges of cells you need and copy and paste them into the appropriate columns in the "**example-data**" sheet of the **Excel-to-KML.xls** file.
4. In the Excel "**example-data**" sheet, paste in column information for each field stop description, name of photos or other illustrations, and captions for these illustrations. Placing each item in a separate column allows us to create a standard format for information that will be displayed in each placemark. Note that getting the data properly into Excel may require some formatting or using the "paste special" command.
5. Number each placemark and organize the trip as desired using the sorting feature in Excel.
6. Lastly, export the finished data from Excel to a KML file using the embedded macro in the **Excel-to-KML.xls** spreadsheet.

The visual appearance of the placemark balloons in Google Earth is determined by HTML formatting, which can be the trickiest part of this whole process. Currently, this HTML format is hard coded into the "**export-to-KML**" macro, and must be manually changed outside of the application's user interface. Thus, some knowledge of how to use the Visual Basic editor is required. In the Visual Basic editor, you can access the editable code by right-clicking on the "KML-Generator" form in the project explorer and selecting "view code." The HTML is fairly easy to find at the top of the code block. The "**export-to-KML**" macro uses URLs to the UGS web server, so at the very least you will simply need to change the base URLs for the images from the UGS Web server to the Web address of your images. We created two different image directories, one for image thumbnails and one for full-sized images.

To aid technical review of the virtual field trip, we maintained the **Excel-to-KML.xls** spreadsheet as our master copy of all field trip stop description and caption text and simply exported those columns into a Word document for review (see "copy-to-word" tab in the **Excel-to-KML.xls** spreadsheet). Reviewers can then view the virtual field trip and also have a copy of the text on which to make comments.

Tour Settings

The behavior of this virtual tour is determined by the settings in Google Earth. The fly-to speed, tour speed, and tour stop duration settings are found in the Tools-Options-Touring menu. We recommend that the user set these parameters so the virtual field trip does not travel too fast between placemarks, and so the terrain will redraw properly. Also, users need to set the tour stop duration long enough to view the photos and read the information in the balloons. The tour can be paused, but since doing so causes the balloon to disappear, the user will need to click on the placemark to renew the balloon; when the user finishes viewing the balloon information they can then resume the tour.

These tour settings are important to configure so that the virtual tour will run as intended by the author. Prominent instructions to the user, for optimal tour settings, must be simple but descriptive. Our suggested settings are included here: *http://geology.utah.gov/geo_guides/st_george/UGS_VirtualFieldGuides_settings.htm*.

Future Possibilities

Google Earth is an excellent platform for disseminating a variety of geologic information. Widespread interest in displaying geoscience data in this manner will undoubtedly ensure that newer and better tools will be developed for this purpose.

In the future, we may:

- Add additional placemarks that serve to highlight the full range of geologic units and structures in the quadrangle.
- Create placemarks to show a variety of geologic hazards and geologic resources information.
- Create several different, possibly theme-based, field trip routes.
- Add links to stratigraphic columns, correlation diagrams, and cross sections.
- Add information balloon links to the complete description of map units.

Postscript

In just one year since working out the above procedure for creating this virtual map and field trip project, there have been many advances in software capabilities. ESRI and Google have both released newer software versions that allow us to streamline this process. Example: Google Earth 5 supports the ability to mouse-click anywhere on attributed polygons to initiate pop-up information balloons. Former versions required attributed point features that you click on to pop-up the balloons; this nice improvement eliminates one production step!

The exploded CAD data can now be formatted and exported directly from ArcMap 9.3 to a KMZ file, using an ArcToolbox tool, eliminating the Global Mapper step used previously for this. The free user-created extension for ArcMap "Export To KML" has been upgraded to version 2.5 and has much better support for HTML layer and feature balloon styles and descriptions. Examples of our virtual map and field trip can be found at *http://geology.utah.gov/geo_guides/st_george/index.htm*.

Software Resources

ArcGIS - ESRI, 380 New York St., Redlands, CA 92373-8100 USA, (909) 793-2853, *http://www.esri.com*.

"Export To KML" - City of Portland, OR, Bureau of Planning, email: *kmartin@ci.portland.or.us*, "Export To KML" is an ArcMap extension available as a free download from ESRI Support Center, *http://arcscripts.esri.com/*.

Global Mapper - Global Mapper Software LLC, 11835 N. Tomahawk Rd., Parker, CO 80138 USA, Email: *support@globalmapper.com*, *http://globalmapper.com*.

Google Earth - Google Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043 USA, (650) 253-0000, *http://earth.google.com*.

Microsoft Office 2003 - Microsoft Corporation, One Microsoft Way, Redmond, WA 98052-6399 USA, (800) 642-7676, *http://www.microsoft.com*.

VrOne - Cardinal Systems LLC, 175 Lehigh Avenue, Flagler Beach, FL 32136 USA, (386) 439-2525, Email: *mike@cardinalsystems.net*, *http://www.cardinalsystems.net*.

Digital Mapping Process of Seismic Design Category Information for Residential Construction in Washington

By Recep Cakir and Timothy J. Walsh

Washington State Department of Natural Resources
Division of Geology and Earth Resources
1111 Washington Street SE, PO Box 47007
Olympia, WA 98504-7007
email: *recep.cakir@dnr.wa.gov* and *tim.walsh@dnr.wa.gov*

Introduction

The 2003 International Residential Code (IRC)(International Code Council, 2003) was adopted in 2004 by the Washington State Legislature as the official state building code for one- and two-family dwellings and townhouses not more than three stories in height and with separate means of egress. Poelstra and Palmer (2004) published seismic design category (SDC) maps, based on this 2003 IRC using the 1996 National Seismic Hazard Maps (Frankel and others, 1996), to assist local building officials, property owners, and developers of residential construction in Washington. The recently published 2006 IRC (International Code Council, 2006a, b), adopted for use in Washington beginning on July 1, 2007, requires changes in previously determined seismic design categories that had been ranked (from lower to higher) as A, B, C, D_0, D_1, D_2, and E. The higher the rank of the SDC, the more restrictive the required building code provisions, which increases the cost of building design and construction. In the 2006 IRC, the former seismic design category D_1 of the 2003 IRC is subdivided into categories D_0 and D_1, as defined in Section R301.2.2, specifically in Table R301.2.2.1.1, of the 2006 IRC (International Code Council, 2006b). In addition, the 2002 National Seismic Hazard Maps (Frankel and others, 2002) were incorporated into the new IRC maps.

Accordingly, two new types of digital map data for seismic design categories are being prepared. These digital data include two ESRI shapefiles that contain information on seismic design categories determined based on (1) the assumption that the entire state is site class D, which is the default value in the IRC where no site class information is available and (2) seismic design categories based on available NEHRP site class information provided by the Washington State Department of Natural Resources (Poelstra and Palmer, 2004).

Calculation Method for Seismic Design Category Maps

To generate seismic design categories, we first calculated S_{DS} values (design spectral response acceleration) at 5 percent critical damping by using the 2003 revision of the U.S. Geological Survey's 2002 short-period (0.2 sec) accelerations (S_S) with 2 percent probability of exceedance in 50 years (Frankel and others, 2002; Nicolas Luco, USGS, written commun., 2007), which represent the maximum considered earthquake (MCE) of standard ASCE/SEI 7-05 (American Society of Civil Engineers, 2006). These 0.05 decimal-degree gridded S_S values can be downloaded in ASCII format from the USGS-HMGP website at *http://earthquake.usgs.gov/research/hazmaps/*.

The following procedure is used for production of maps showing seismic design categories of the geologic materials:

1. The maximum considered earthquake (MCE) spectral response acceleration values for short periods (S_S) are adjusted for site class effect (S_{MS}) using the following equation (International Code Council, 2006a, section 1613.5.3):

$$S_{MS} = F_a S_s \qquad (1)$$

where S_S is the mapped spectral acceleration for short periods (0.2 sec) and F_a is the site coefficient defined from Table 1 (default site class D is shaded).

Table 1. F_a site coefficients given in the IBC 2006 (International Code Council, 2006a).

Site class	Mapped spectral response acceleration at short periods				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	*	*	*	*	*

2. The 5 percent damped design spectral response acceleration (S_{DS}) at short periods is determined from the following equation (International Code Council, 2006a, section 1613.5.4):

$$S_{DS} = \frac{2}{3} S_{MS} \qquad (2)$$

3. Finally, we determined the seismic design categories using the S_{DS} values (Table 2).

Table 2. Seismic design categories described in given in Table R301.2.2.1.1 of the 2006 IRC (International Code Council, 2006b).

Seismic Design Category	Calculated SDS (g)
A	$S_{DS} \le 0.17$
B	$0.17 < S_{DS} \le 0.33$
C	$0.33 < S_{DS} \le 0.50$
D0	$0.50 < S_{DS} \le 0.67$
D1	$0.67 < S_{DS} \le 0.83$
D2	$0.83 < S_{DS} \le 1.17$
E	$S_{DS} > 1.17$

Processing Steps for Seismic Design Category Map Data Using Default Site Class D

This dataset is generated using two principal software applications: Microsoft Excel and ESRI ArcGIS. A flowchart (Figure 1) shows processing steps and associated software with related script names (Cakir and Walsh, 2007):

1. Input is gathered from the U.S. Geological Survey (USGS) National Seismic Hazard Maps website (*http://earthquake.usgs.gov/research/hazmaps/*), which is the 2003 revision of the USGS 2002 short-period (0.2 sec) accelerations (S_S) having a 2 percent probability of exceedance in 50 years. These acceleration values are in ASCII format.
2. By using equations (1) and (2) as described in section 1613 of the 2006 International Building Code (IBC), S_s input values, and the assumption for a default site class D, we calculated S_{ds} values in Microsoft Excel.
3. We then converted these S_{ds} values from Excel to an ESRI (ArcGIS) point shapefile.
4. This shapefile was later converted to an ArcGIS grid with a 100-foot cell size.
5. By using a MapAlgebra script in the Spatial Analyst Tool of the ArcGIS, we then assigned seismic design categories in numerical form because grid-based calculation requires values (in a subsequent step, letter class designations are assigned in ArcMap).
6. We then converted this grid file to a polygon shapefile and assigned seismic design categories given in Table 2.
7. Finally, we generated the seismic design category map by dissolving this polygon shapefile. Likewise for the Poelstra and Palmer (2004) seismic design category map, we also used site class F (peat deposits) as an overlay on this final dissolved map. (Note that site class F includes peat deposit sites which may or may not liquefy, therefore requiring detailed geotechnical investigation.)

Processing Steps for Seismic Design Category Map Data Using an Available Seismic Site Class Map

This dataset generation uses the statewide NEHRP site class map (Palmer and others, 2007). Site class values are combined with short period accelerations from the 2002 version of the USGS National Seismic Hazard Map to yield seismic design values in the manner prescribed in the IRC 2006. This dataset is intended to aid the end users who want to implement the changes in seismic design categories given in the 2006 IRC.

Site class F attribute data directly excluded from the NEHRP site class map were joined to seismic-design categories. Site class F represents peat deposits, which require detailed geotechnical investigations. The user may also

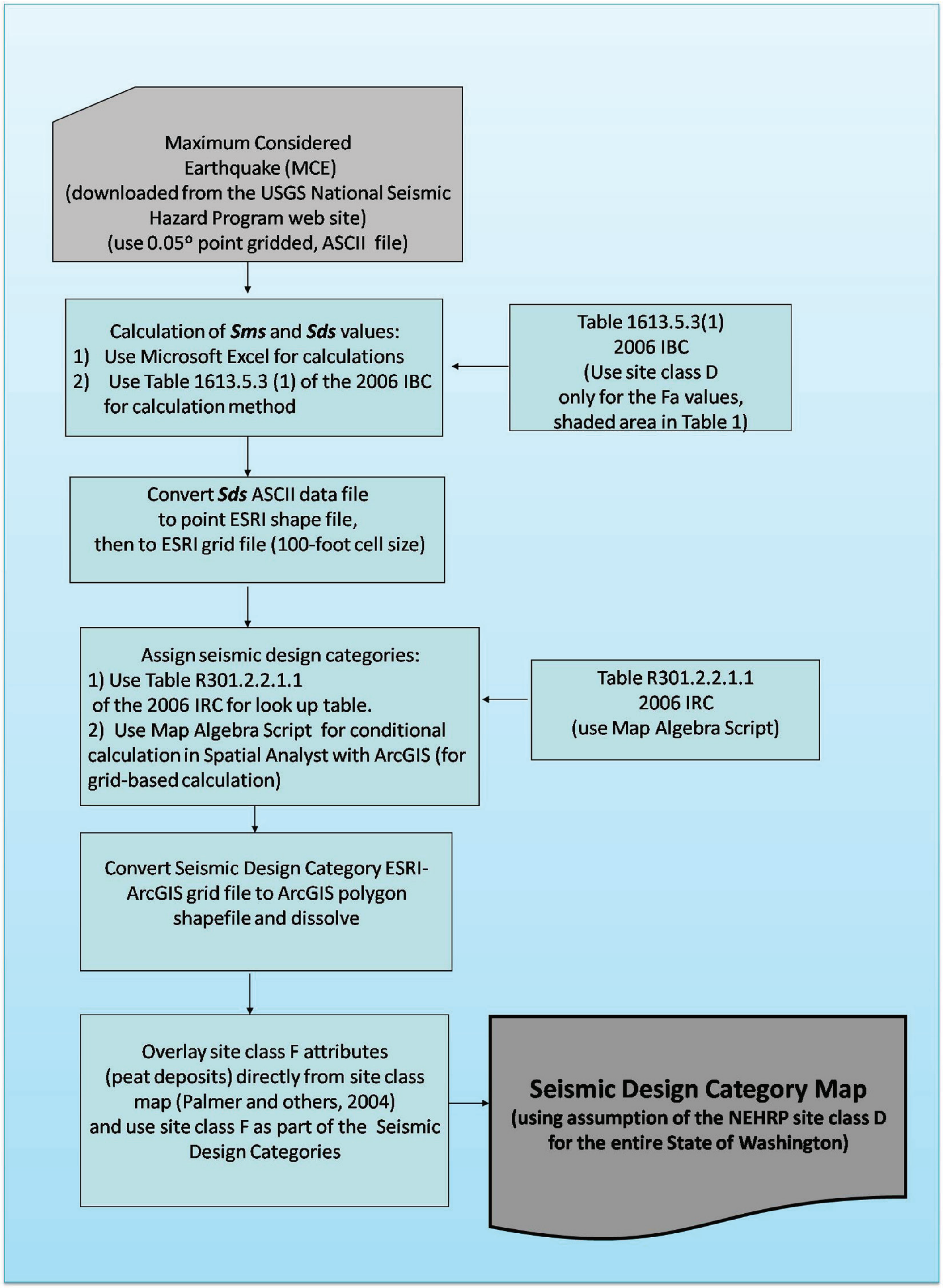


Figure 1. Flowchart showing the processing steps for generating seismic design categories with assumption of the assigned NEHRP site class D for Washington State.

incorporate the liquefaction susceptibility map (Palmer and others, 2007), which is not presented in our seismic design categories, to determine other areas that could be considered to be site class F based on their potential for liquefaction failure during an earthquake.

This dataset is generated using ESRI ArcGIS software (*http://www.esri.com*). A flowchart (Figure 2) shows processing steps. To produce seismic design categories with inclusion of the statewide NEHRP site class information (Palmer and others, 2007) the following steps were used:

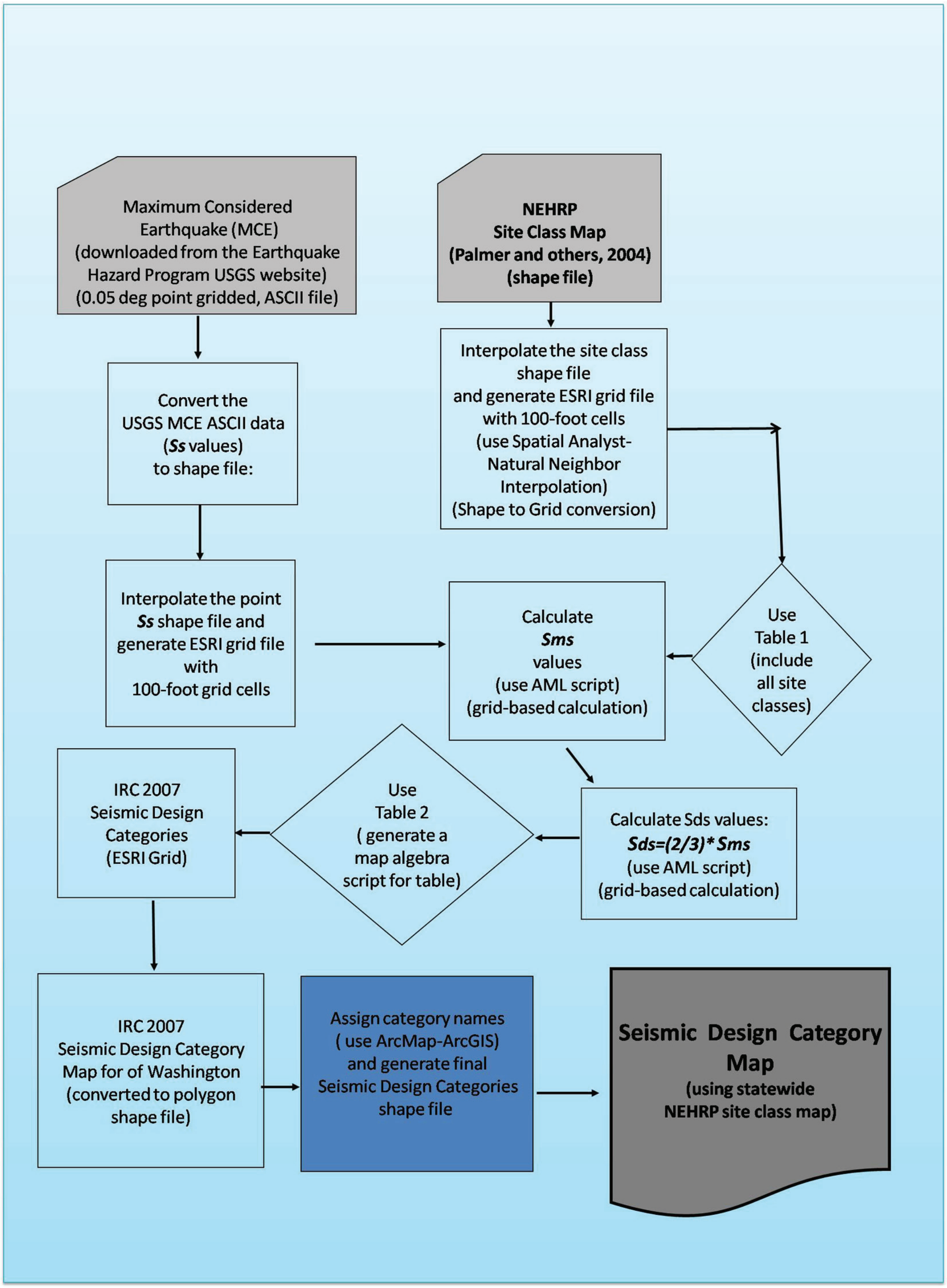


Figure 2. Flow chart showing processing steps for generating seismic design categories using the available NEHRP site class map produced by Palmer and others (2007).

1. Inputs were gathered from (a) the USGS National Seismic Hazard Maps website (*http://earthquake.usgs.gov/research/hazmaps/*), which is the 2003 revision of the USGS 2002 short-period (0.2 sec.) accelerations (S_S) having a 2 percent probability of exceedance in 50 years (these acceleration values are in ASCII format) and (b) the NEHRP seismic site class map (Palmer and others, 2004) converted to a 100-foot ESRI grid. These two inputs and their processing steps are shown in Figure 2.

2. Equations (1) and (2), as also described in section 1613 of the 2006 IBC, were used to calculate S_{ds} values for assigning the seismic design categories. We calculated S_{DS} values using an AML script.

3. Using a MapAlgebra script in Spatial Analyst Tool of ArcGIS, we then assigned seismic design categories.

4. We then converted this grid file to polygon shapefile and assigned seismic design categories given in Table 2.

5. Finally, we generated the seismic design category map by dissolving this polygon shapefile and directly overlaying the site class F, which requires detailed geotechnical investigation. One must note that site class F includes peat deposits. Here the site class F (representation of peat deposits) attribute is directly extracted from site class map (Palmer and others, 2007).

After generating the shapefiles of the seismic design categories, demographic information used as an overlay and graphical editing were completed to generate final static maps (Figures 3 and 4) (Cakir and Walsh, 2007). In addition, Arc geodatabase (SDE and .mxd files) are generated from the shapefiles. Finally, these IRC maps are presented on the Washington Division of Geology and Earth Resources interactive mapping site (*http://wigm.dnr.wa.gov/*; Figure 5).

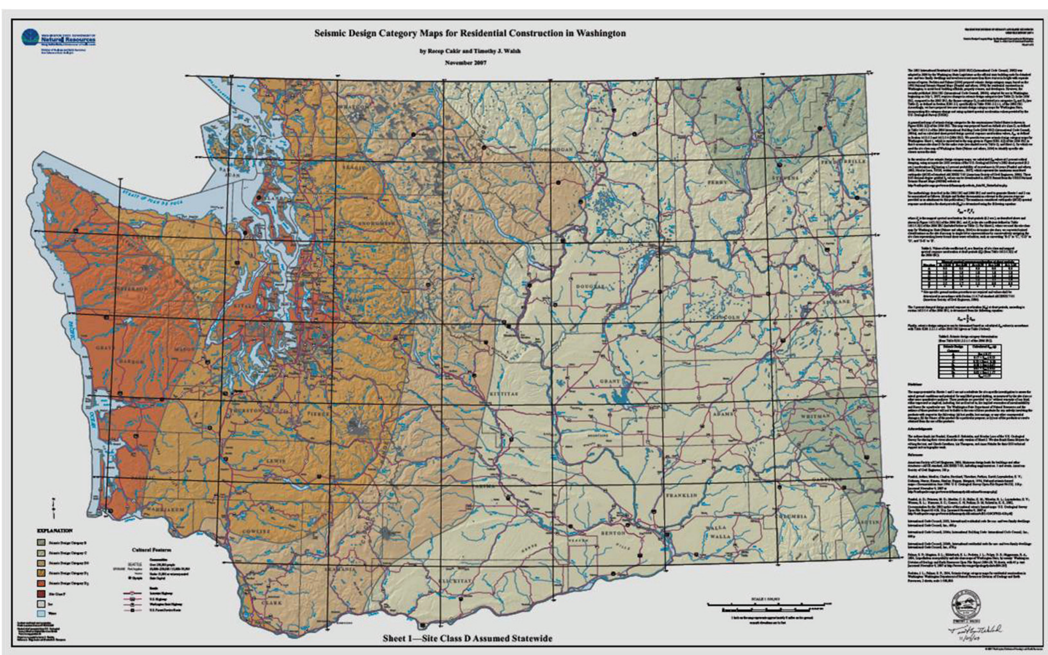


Figure 3. Seismic design category map with the assumption of site class D (Cakir and Walsh, 2007).

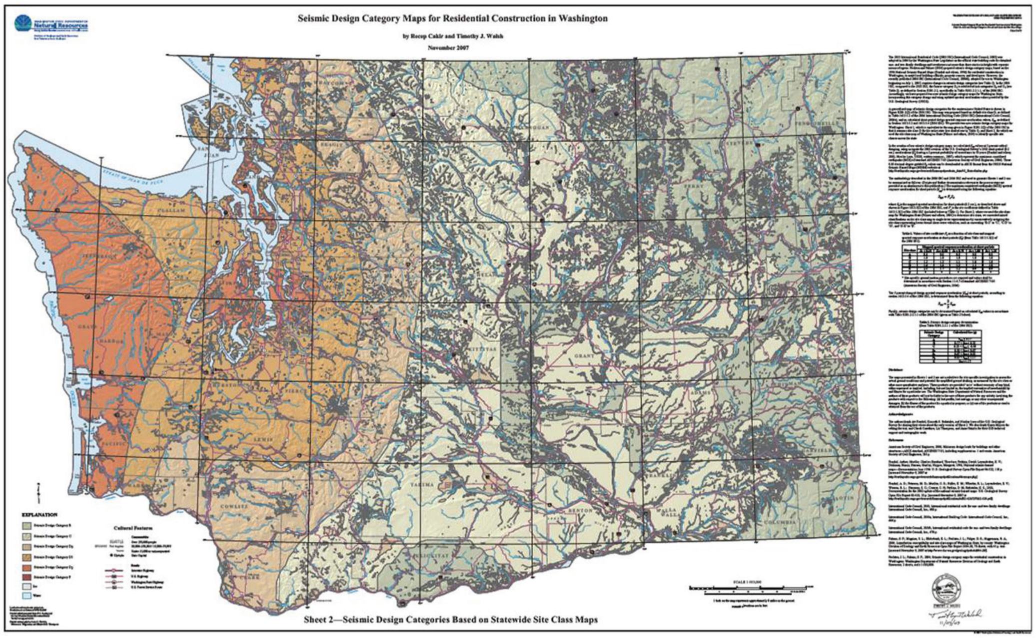


Figure 4. Seismic design category map using the NEHRP site class map for Washington State (Cakir and Walsh, 2007).

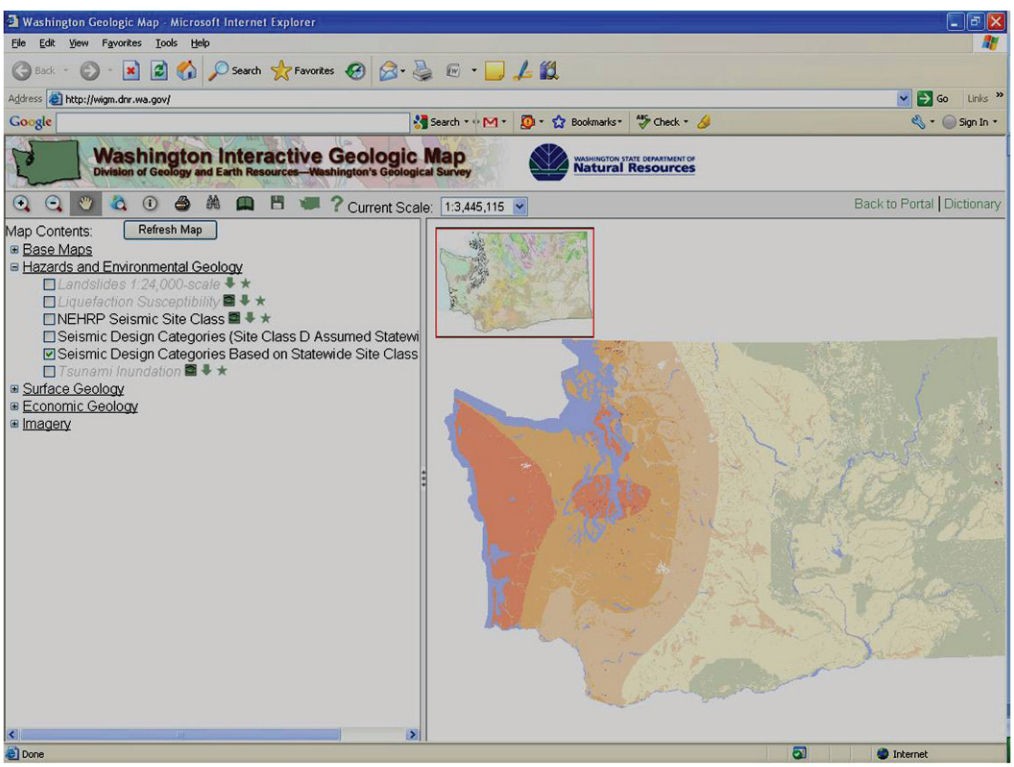


Figure 5. Washington Division of Geology and Earth Resources interactive mapping site (*http://wigm.dnr.wa.gov/*).

Conclusions

Two new types of digital map data for seismic design categories are being prepared to assist local building officials, property owners and developers in Washington State. These digital data include two ESRI shapefiles that contain information on seismic design categories determined, based on (1) the assumption that the entire state is site class D, if no site class information is available and (2) available statewide NEHRP site class information provided by the Washington State Department of Natural Resources (Poelstra and Palmer, 2004; Cakir and Walsh, 2007).

The default (first) site class D map that we generated in digital form provides a better and more manageable (in terms of digital map data manipulations such as zoom in and out, and overlay capacities) compared to the paper map given in Figure R301.2(2) of the 2006 IRC (International Code Council, 2006b). The second seismic design category map data present more realistic seismic design categories incorporating seismic site effects, in relation to local geology, based on the NEHRP site class map of Washington State. These two versions of the IRC digital map data are available through Washington State Geologic Information Portal – Interactive Mapping server (*http://wigm.dnr.wa.gov/*) and ftp site, which give users a variety of options to print out and view more presentable maps.

Acknowledgments

We thank Karen D. Meyers, Anne C. Heinitz, Elizabeth E. Thompson, Charles G. Caruthers, and Jaretta M. Roloff for the graphical, text and GIS editing of the 2006 IRC maps, and David K. Norman for his support for the management of the preparation of the maps.

References

American Society of Civil Engineers, 2006, Minimum design loads for buildings and other structures: American Society of Civil Engineers (ASCE) Standard, ASCE/SEI 7-05, 388 p.

Cakir, Recep, and Walsh, T.J., 2007, Seismic design category maps for residential construction in Washington: Washington Division of Geology and Earth Resources Open File Report 2007-4, 2 plates, accessed at *http://www.dnr.wa.gov/Publications/ger_ofr2007-4_seismic_design_categories.zip*.

Frankel, A.D., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M., 1996, National seismic-hazard maps—Documentation (June 1996): U.S. Geological Survey Open-File Report 96-532, 110 p., *http://pubs.usgs.gov/of/1996/532/*.

Frankel, A.D., Petersen, M.D., Mueller, C.S., Haller, K.M., Wheeler, R.L., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Cramer, C.H., Perkins, D.M., and Rukstales, K.S., 2002, Documentation for the 2002 update of the national seismic hazard maps: U.S. Geological Survey Open-File Report 02-420, 33 p., *http://pubs.usgs.gov/of/2002/ofr-02-420/*.

International Code Council, 2003, International residential code for one- and two-family dwellings: International Code Council, Inc., 608 p.

International Code Council, 2006a, International building code: International Code Council, Inc., 666 p.

International Code Council, 2006b, International residential code for one- and two-family dwellings: International Code Council, Inc., 670 p.

Palmer, S.P., Magsino, S.L., Bilderback, E.L., Poelstra, J.L., Folger, D.S., and Niggemann, R.A., 2004, Liquefaction susceptibility and site class maps of Washington State, by county: Washington Division of Geology and Earth Resources Open File Report 2004-20, 1 DVD [78 plates, 45 p. text], accessed Oct. 1, 2007 at *http://www.dnr.wa.gov/ResearchScience/Topics/GeologyPublicationsLibrary/Pages/pub_ofr04-20.aspx*.

Poelstra, J. L., and Palmer, S.P., 2004, Seismic design category maps for residential construction in Washington: Washington Department of Natural Resources Division of Geology and Earth Resources, 2 sheets, scale 1:500,000.

U.S. Geological Survey National Seismic Hazard Mapping Program, accessed May 1, 2009 at *http://earthquake.usgs.gov/research/hazmaps/*.

Digital Map Production and Publication at the Geological Survey of Alabama

By Philip A. Dinterman

Geological Survey of Alabama
P.O. Box 869999
Tuscaloosa, AL 35486
Telephone: (205) 247-3559
Fax: (205) 349-2861
email: *pdinterman@gsa.state.al.us*

Introduction

The Geological Survey of Alabama (GSA) is currently conducting geologic mapping at 1:24,000 scale (7.5-minute topographic quadrangle maps) in conjunction with the U.S. Geological Survey's (USGS) STATEMAP program. On average, the GSA is mapping three quadrangles each field season. These maps are compiled digitally, and a paper copy is completed and submitted to the USGS as a contract deliverable map. The map then goes through an internal GSA review and is published as a Quadrangle Series Map that includes a map report. The GSA has published 50 Quadrangle Series Maps that were supported in part by the STATEMAP program and, previously, by the Tennessee Valley Authority. The process of creating and updating digital databases for all of these quadrangles is ongoing.

Many of these maps either have been compiled in a digital format or have been converted into a digital format. There are two processes running concurrently: (1) the creation of new geologic maps and digital databases, and (2) the updating of previously published maps into a current digital format. Currently, the GSA is releasing data in three formats. The first is a database package using Environmental Systems Research Institute (ESRI)-supported geodatabases. The second is a shapefile package, with most of the same available data; these files can be used with most GIS software. The final package includes a PDF of the map and map explanation. Metadata are written for all of the digital data that the GSA has created. The release of geodatabases, shapefiles, and PDF files via the GSA website began in 2007. The only part of the publication not released within these three packages is the map report, which is available for purchase in the GSA Publications Sales office. The goal is to release the digital files of all of the previous and future STATEMAP quadrangles to the public.

Collection of Data

Field mapping is still dominantly rooted in traditional (nondigital) data collection techniques. The geologic mappers at the GSA take a paper copy of the quadrangle into the field and collect data points using a hand-held GPS, Brunton compass, and barometric altimeter. Locations of observations are plotted on the field sheet (Figure 1) and the observations are written in a field notebook. Then in the office, the location points commonly are transcribed to a paper copy of the map. Sometimes, rather than transcribing to a paper copy in the office, the observations are directly entered into a GIS format as points (Figures 2 and 3).

Recently, a handheld Trimble GeoExplorer XM has been purchased to collect digital data in the field. This unit is being tested for the possible collection of more detailed and complex information, and for integration of digital data in the field. Currently, observation points are collected in this device with ArcPad 7.1 and then compiled in the office into an ArcGIS database. These observation points coincide with those collected and transcribed on the hardcopy map sheet.

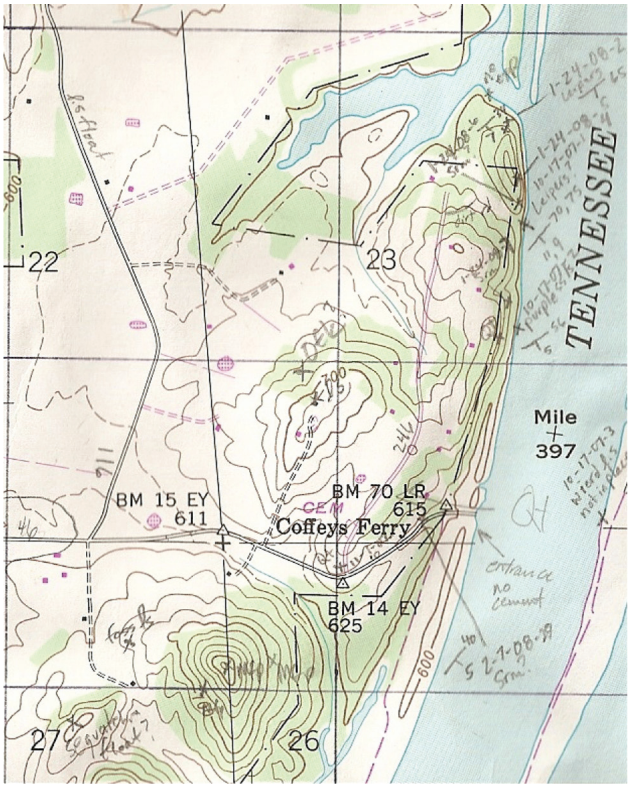


Figure 1. Field sheet with locations.

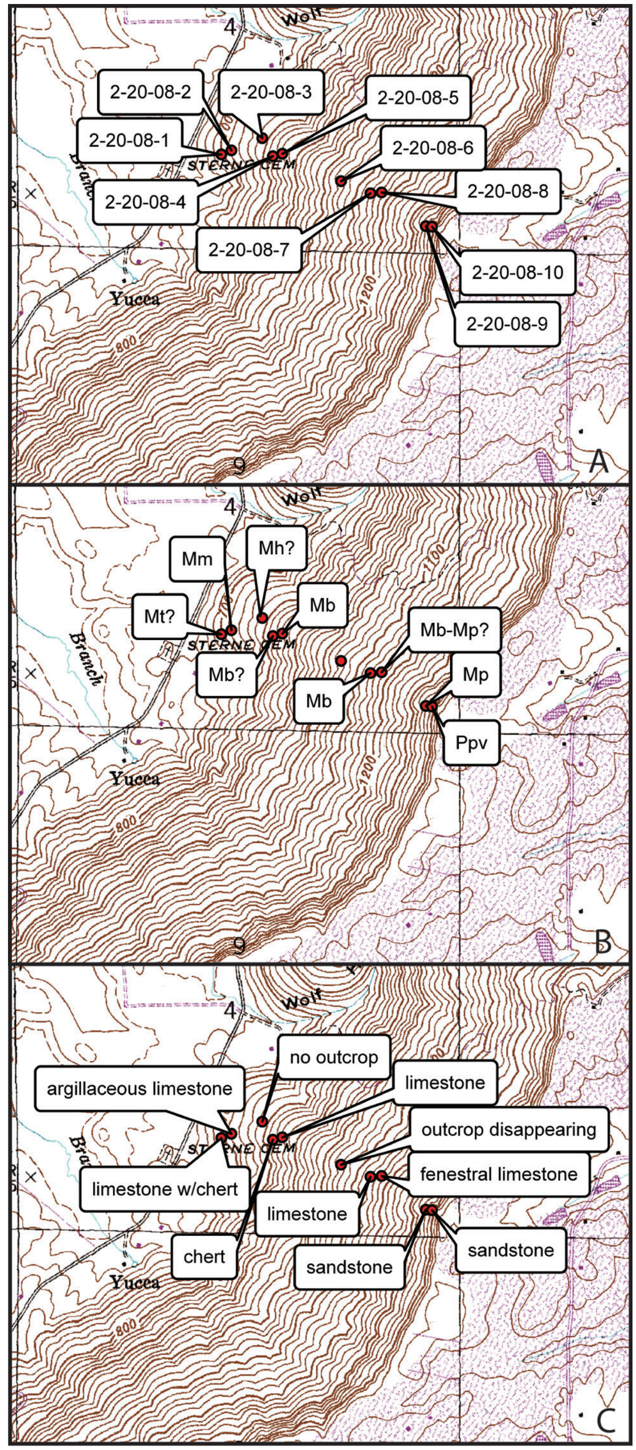


Figure 2. Three labeling schemes used to help make interpretations of geologic units and contacts. A. Observation points, date used as identifier. B. Field-interpreted geologic units. C. Lithology of rocks at each observation point.

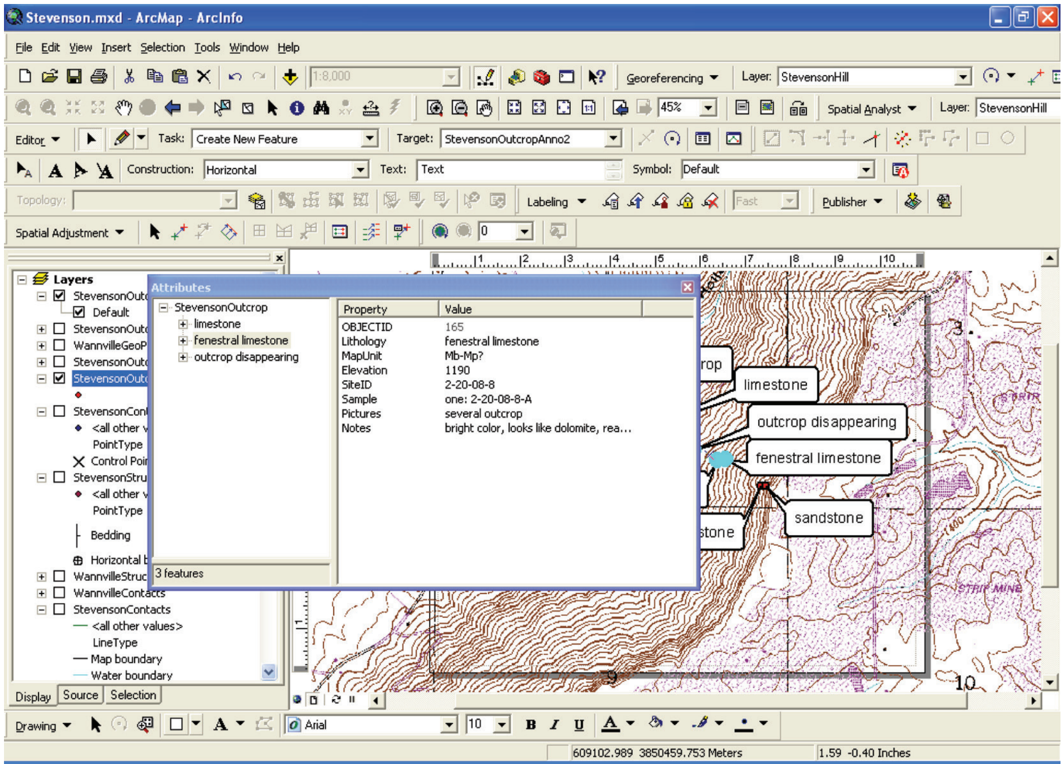


Figure 3. Attributes entered from field observations. At each location the lithology, probable geologic unit, altitude (from altimeter), sample ID, samples and/or pictures taken, and notes associated with that location are recorded.

Compilation of Data

The field data are compiled by first creating in ArcCatalog a geodatabase with the desired feature classes and attributes (Table 1). Then, using a georeferenced USGS topographic map as a basemap, data points from field observations are entered into the database as a map of outcrops (Figure 2). For display purposes the background colors (green and white) of the topographic tiff image are turned to a null value; later, when the map is being prepared for publication, the base is set to a desired transparency level overlain on the geologic polygons layer. Along with the outcrop points, structural points and control points are entered where these observations were taken. At present, the outcrop points are only being used in the map construction process and are not

Table 1. Features, layers, and data currently used in GSA maps.

LAYERS	FEATURES	DATA
Points	***Structural Points***	Type of point, strike and dip values
	Control Points	Locations where contacts between two units are identified
Lines	***Contacts***	Geologic contacts, faults, and water boundaries
	Structural Lines	Anticlines and synclines
	Cross Section	Cross sections
Polygons	***Geology Polygons***[1]	Geologic units (map unit name)
		Map unit abbreviations
		Age
Annotation	***Contacts***	Full name of feature (most commonly, faults and structural lines)
	Structural Lines	
	Structural Points	Dip values on structural points
	Geology Polygons	Map unit abbreviations

[1] Unit descriptions are found in the metadata.

being released with the final digital files. The next step is the construction of geologic contacts and structural lines. Two methods have been used. The first entails drawing the lines on a clean paper copy of the topographic base. The map is then scanned on a large format scanner, georeferenced in ArcMap, and digitized from this scan. The other method is to heads-up digitize on the screen in ArcMap using the outcrop map as a guide. When available, hydrologic lines are downloaded from various sites and used as a control for mapping. Quaternary alluvium contacts are drawn using both field observations and county soil surveys (Figure 4). Polygons of geologic units are then constructed from the lines.

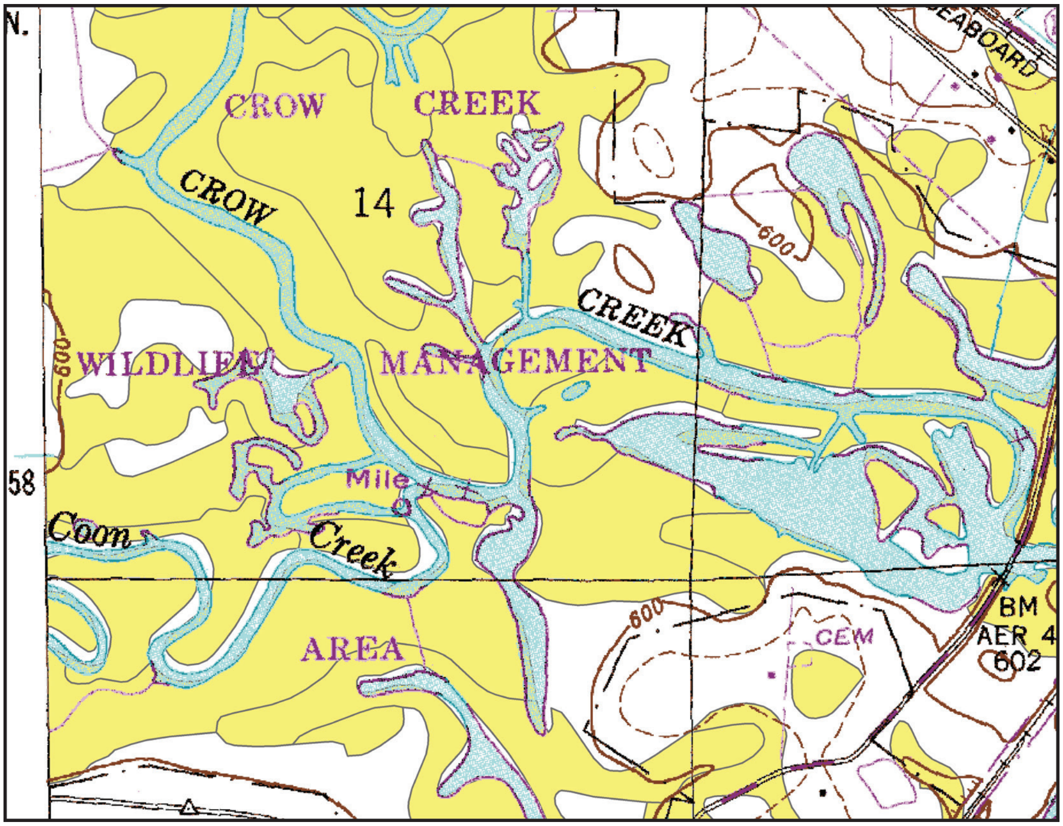


Figure 4. Soil data from county surveys. Alluvial soils are used to constrain location of Quaternary alluvium deposits.

Construction of Map and Database

Once the field observations and interpretations are entered, the database is populated with the desired attribute data (Table 1 and Figures 5-8). After the population of all features is complete, feature-linked annotation is constructed in ArcMap as necessary. Commonly, annotation includes the dip numbers for the structural points, map units for the geologic polygons, and names for specified lines such as names on faults and structural cross section lines. The feature-linked annotation in ArcMap allows for easy movement of the annotation to desired positions on the map. Additionally, when changes are made to attributes, the feature-linked annotation is automatically updated, reducing the chance for label errors on the map.

The attributes in the GSA database continue to evolve, and we are making efforts to integrate the North American Geologic Map Data Model (NADM). Currently, the following attributes are included in newly constructed GSA database layers (see also Table 1):

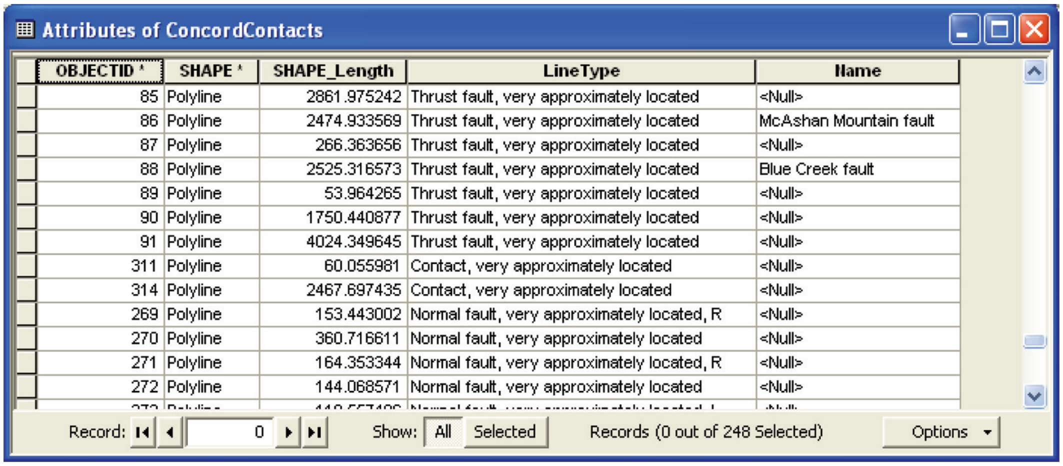
Attributes of ConcordGeologyPolygons

MapUnit	Age	Unit
Oc	Middle Ordovician	Oc, Chickamauga Limestone
Qal	Quaternary	Qal, Alluvium
Srm	Lower and Upper Silurian	Srm, Red Mountain Formation
Oc	Middle Ordovician	Oc, Chickamauga Limestone
Mh	Upper Mississippian	Mh, Hartselle Sandstone
Srm	Lower and Upper Silurian	Srm, Red Mountain Formation
Mpm	Upper Mississippian	Mpm, Pride Mountain Formation
Mfb	Upper Mississippian	Mfb, Floyd Shale and Bangor Limestone undifferentiated
Mtfpm	Lower and Upper Mississippian	Mtfpm, Tuscumbia Limestone, Fort Payne Chert, and Maury Formation undifferentiated
Mh	Upper Mississippian	Mh, Hartselle Sandstone
Srm	Lower and Upper Silurian	Srm, Red Mountain Formation
Mtfpm	Lower and Upper Mississippian	Mtfpm, Tuscumbia Limestone, Fort Payne Chert, and Maury Formation undifferentiated
Mh	Upper Mississippian	Mh, Hartselle Sandstone
Mtfpm	Lower and Upper Mississippian	Mtfpm, Tuscumbia Limestone, Fort Payne Chert, and Maury Formation undifferentiated
Mfb	Upper Mississippian	Mfb, Floyd Shale and Bangor Limestone undifferentiated

Record: 1 Show: All Selected Records (0 out of 73 Selected) Options

Figure 5. Attribute table for geologic units. Attributes include map unit abbreviation, unit name, and age.

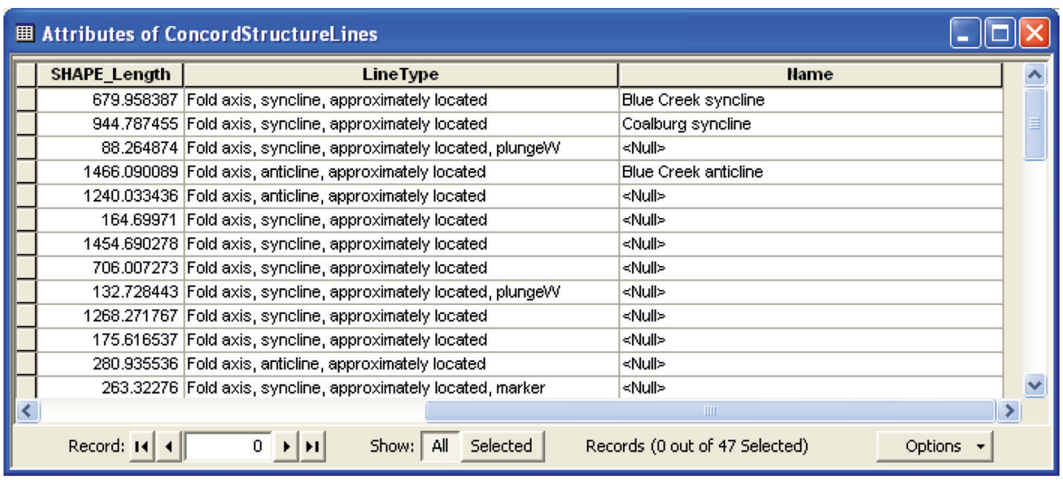
- *Geology Polygons* – Map unit (the map unit abbreviation), Unit (Name of geologic unit), and Age (see Figure 5)
- *Contacts, Cross Section and Structural Lines* – Line type and name (see Figures 6 and 7)
- *Structure Points* – Point type, Strike, and Dip (see Figure 8)
- *Control Points* – Point type, elevation (when available) and geologic units (if necessary)


Attributes of ConcordContacts

OBJECTID *	SHAPE *	SHAPE_Length	LineType	Name
85	Polyline	2861.975242	Thrust fault, very approximately located	<Null>
86	Polyline	2474.933569	Thrust fault, very approximately located	McAshan Mountain fault
87	Polyline	266.363656	Thrust fault, very approximately located	<Null>
88	Polyline	2525.316573	Thrust fault, very approximately located	Blue Creek fault
89	Polyline	53.964265	Thrust fault, very approximately located	<Null>
90	Polyline	1750.440877	Thrust fault, very approximately located	<Null>
91	Polyline	4024.349645	Thrust fault, very approximately located	<Null>
311	Polyline	60.055981	Contact, very approximately located	<Null>
314	Polyline	2467.697435	Contact, very approximately located	<Null>
269	Polyline	153.443002	Normal fault, very approximately located, R	<Null>
270	Polyline	360.716611	Normal fault, very approximately located	<Null>
271	Polyline	164.353344	Normal fault, very approximately located, R	<Null>
272	Polyline	144.068571	Normal fault, very approximately located	<Null>

Record: 0 Show: All Selected Records (0 out of 248 Selected) Options

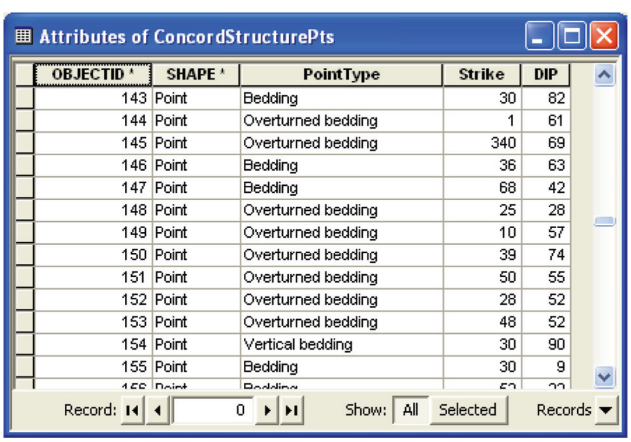
Figure 6. Attribute table for geologic contacts. Attributes include type of contact or fault, and name of feature, if any.


Attributes of ConcordStructureLines

SHAPE_Length	LineType	Name
679.958387	Fold axis, syncline, approximately located	Blue Creek syncline
944.787455	Fold axis, syncline, approximately located	Coalburg syncline
88.264874	Fold axis, syncline, approximately located, plungeW	<Null>
1466.090089	Fold axis, anticline, approximately located	Blue Creek anticline
1240.033436	Fold axis, anticline, approximately located	<Null>
164.69971	Fold axis, syncline, approximately located	<Null>
1454.690278	Fold axis, syncline, approximately located	<Null>
706.007273	Fold axis, syncline, approximately located	<Null>
132.728443	Fold axis, syncline, approximately located, plungeW	<Null>
1268.271767	Fold axis, syncline, approximately located	<Null>
175.616537	Fold axis, syncline, approximately located	<Null>
280.935536	Fold axis, anticline, approximately located	<Null>
263.32276	Fold axis, syncline, approximately located, marker	<Null>

Record: 0 Show: All Selected Records (0 out of 47 Selected) Options

Figure 7. Attribute table for structural lines. Attributes include linetype of structural line and name of feature, if any.


Attributes of ConcordStructurePts

OBJECTID *	SHAPE *	PointType	Strike	DIP
143	Point	Bedding	30	82
144	Point	Overturned bedding	1	61
145	Point	Overturned bedding	340	69
146	Point	Bedding	36	63
147	Point	Bedding	68	42
148	Point	Overturned bedding	25	28
149	Point	Overturned bedding	10	57
150	Point	Overturned bedding	39	74
151	Point	Overturned bedding	50	55
152	Point	Overturned bedding	28	52
153	Point	Overturned bedding	48	52
154	Point	Vertical bedding	30	90
155	Point	Bedding	30	9

Record: 0 Show: All Selected Records

Figure 8. Attribute table for structural points. Attributes include structural point type, strike (using 0-360 azimuth), and dip.

Construction of the cross section is still done by a primarily nondigital process. Until recently, only 30-meter DEMs were available in the current mapping area, which provide too coarse a topographic surface profile for some available cross-section building programs. The desired line is drawn on the map and the elevations are gleaned from the topographic base and transferred to a piece of graph paper to get the surface profile. The cross section is then drawn using structural observations and known or approximate thicknesses of units. After the cross section is completed by hand, it is scanned, drawn in Adobe Illustrator, and then added to the layout. Compiled 10-meter DEMs are now available for areas to be mapped in the upcoming year, and GSA is hoping to digitally generate a topographic surface profile using those data.

Metadata

Metadata are written within ArcCatalog for each feature class and then are exported in text (.txt) format. Similar information in each feature class (citation, distribution, etc.) is completed only once in ArcCatalog and then is copied and pasted into each feature class's metadata in Notepad. Metadata for each feature class are completed in Notepad and then are imported back into ArcCatalog for each feature class. Finally, metadata that include information from all feature classes are compiled in Notepad and then imported at the Geodatabase and Feature Dataset levels.

Overall, the objective to put most, if not all, of the data in the database is an ongoing process. The most important data that are found only in the metadata are the geologic unit descriptions (Figure 9). Preferably, these data would be in the GeologyPolygons feature class/shapefile, but a suitable presentation for the data is unknown. There is no word wrap feature in the attribute table, and users would have to scroll laterally through a single line to read the description.

Layout

Because a paper map is required for both the STATEMAP contract and for GSA publication, and because the layout capabilities of Adobe Illustrator are superior to those of ArcMap, the map is exported out of ArcMap as an .ai file, and the layout is constructed in Illustrator. This step, however, is necessary only if a paper product is generated.

For the digital layout in ArcMap as both .mxd and Published Map Files (PMF), the feature classes are added with annotation feature classes placed in a layer and the geologic units in another layer. All layers are symbolized using a customized style that is released with the database. For display purposes the geologic units (GeologyPolygons) layer is organized by geologic age – each geologic age is added (same feature class added multiple times only for symbolization purposes) and symbolized separately (Figure 10A). Also, the cross section is provided as a hyperlink (as a PDF) in the .mxd and PMF files in the database package (Figure 10B).

Publication of Map and Database

When the database and layout are ready for publication, a formal review process begins. The database goes through a digital review that includes examination of the database, metadata, and associated files. The map layout goes through an editorial review, and any changes that may affect the database are addressed. Once the review process is complete, final preparation of the publication package is undertaken. Metadata are imported back to the geodatabase, into the appropriate feature classes. A published map file package (PMF) is created, final PDFs of the layout are generated, and feature classes are exported to shapefiles for the shapefile package. The data are then posted to the GSA website (*http://www.gsa.state.al.us/gsa/gis_data.aspx*).

The digital data for GSA Quadrangle Series Maps consist of:

1. A Geodatabase package that contains geologic vector and table data stored as data objects within an ESRI personal geodatabase format, raster data stored as ESRI format DRG-TIFF, an ESRI map document for use with ArcGIS 9.3 (which allows full control of editing and rendering of the data sources), and an ESRI-published map document for use with ArcReader, which allows viewing and querying of the source data along with metadata and an ArcGIS style for symbolizing the map.
2. A shapefile package that contains shapefiles exported from the personal geodatabase and the same ESRI DRG-TIFF as in the Geodatabase package along with supporting files. This package does not contain annotation layers included in the Geodatabase package, owing to software limitations.
3. A .txt file with metadata for the entire database. (Metadata are also included within the GIS files.)
4. A PDF file of the map sheet and a PDF file of the cross section and map explanation.
5. A Readme file explaining data, construction of the map as it appears in the .mxd and .pmf, and location and placement of accessory files.

Future

The recent purchase of a hand-held device for digital field-data collection has initiated a potential change in basic data-collection techniques. The evaluation of this device will

Attribute:
Attribute_Label: **UNIT**
Attribute_Definition: **Stratigraphic Unit Description**
Attribute_Definition_Source: Author
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: **Qal, Alluvium**
Enumerated_Domain_Value_Definition: Unconsolidated sand, silt, clay, and angular to rounded chert gravel.
Enumerated_Domain:
Enumerated_Domain_Value: **Ppv, Pottsville Formation**
Enumerated_Domain_Value_Definition: Light-gray, medium- to coarse-grained, quartzose sandstone locally containing scattered to abundant well-rounded quartz pebbles; quartz pebbles and/or claystone conglomerate locally present. Interbeds and intervals of dark-gray shale and mudstone and wavy- to lenticular-bedded sandstone and shale locally present.
Enumerated_Domain:
Enumerated_Domain_Value: **Mp, Pennington Formation**
Enumerated_Domain_Value_Definition: Lower part dominated by light-greenish-gray to light-bluish-gray, conchoidally fractured dolomicrite containing nodules and stringers of dark-gray chert and thin interbeds of dark-gray and greenish-gray shale and mudstone. Middle part includes variably gray, bioclastic limestone; cherty, argillaceous limestone; limey dolomite; and dolomite containing intervals of maroon and olive-green mudstone. In the southern part of the quadrangle, the uppermost part consists of interbedded maroon and olive-green shale and mudstone. On Keel Mountain, the uppermost part is dark-gray shale, wavy- to lenticular-bedded sandstone and mudstone, ripple-laminated sandstone, and shaly coal.
Enumerated_Domain:
Enumerated_Domain_Value: **Mb, Bangor Limestone**
Enumerated_Domain_Value_Definition: Predominantly light- to locally dark-gray, bioclastic and oolitic limestone. Medium- to dark-gray shale containing thin to discontinuous interbeds of medium-dark-gray, fossiliferous limestone common at base. Lower part includes medium-gray peloidal and fenestral limestone, light-gray dolomicrite, and thin interbeds of light-olive-green shale. Uppermost part includes interbeds of cherty limestone, olive-green and maroon mudstone, and grayish-yellow dolomicrite.

Figure 9. Example of geologic unit descriptions within the metadata.

influence mapping at the GSA. It is the hope of the GSA staff that a suitable and more efficient system will be devised using this hand-held device. This will eliminate a transcription step and hopefully allow for an expansion of database capabilities of the maps. Also, more immediate updates include the expansion of available hyperlinks, mostly in the form of field photographs added to the map databases.

The other major issue that needs to be addressed is the use of base maps. The scanned USGS topographic map is the base map currently used by the GSA. These base maps are not adequate, and although alternatives are being evaluated, none have yet proven cost effective. Agency discussions on this matter have begun and suggestions include higher quality topographic bases, whether scanned by the GSA or from another source. The State of Alabama has begun discussing the collection of LiDAR for the state, and this holds promise for the future. Improving the quality and integrity of the base maps will remain an issue until a satisfactory alternative is reached.

A.
B.

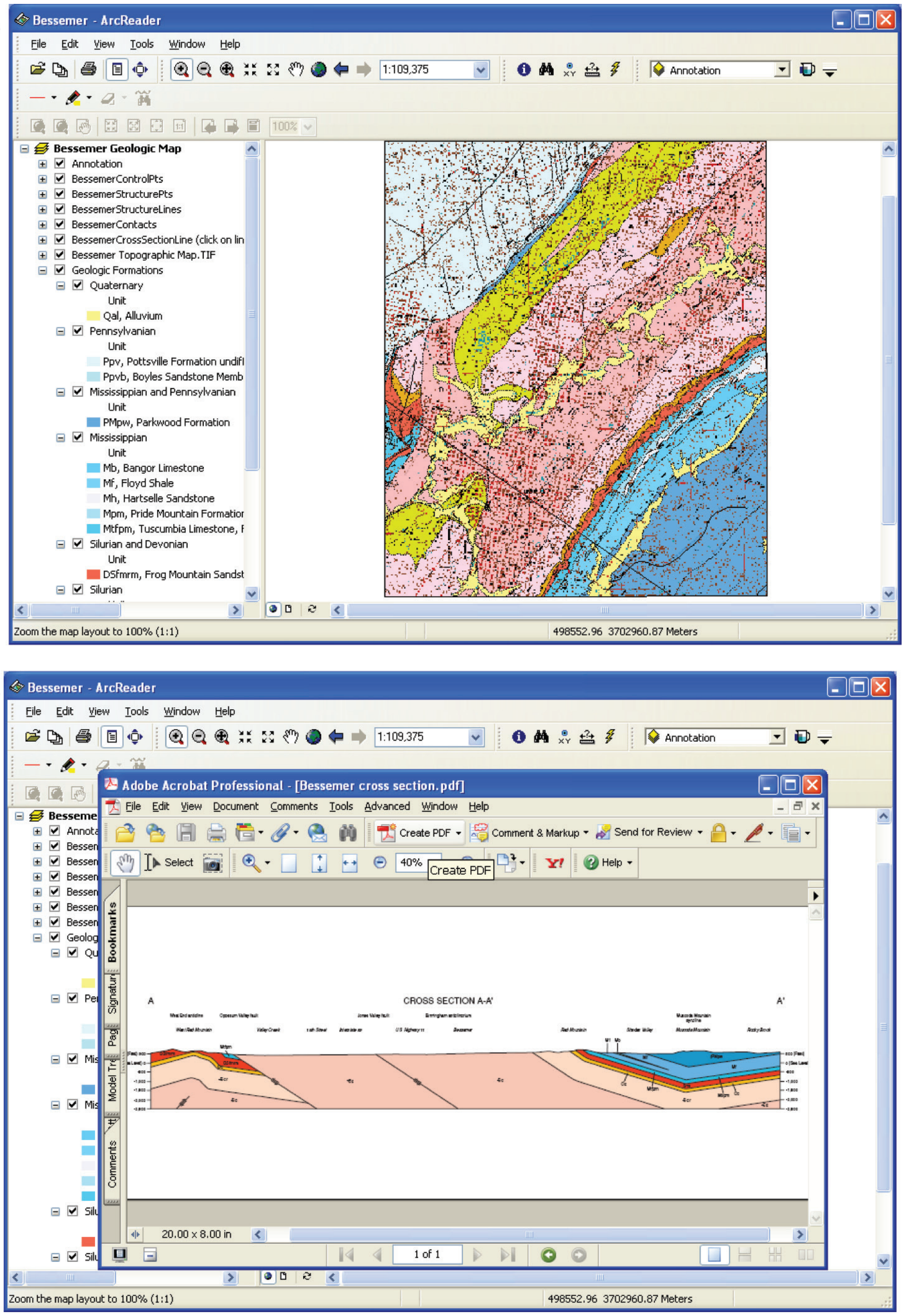


Figure 10. A. Layout of digital geologic map (same layout in both .mxd and PMF). B. View of cross section as it appears from hyperlink.

Creating Geologic Maps for the Appalachian Plateau in a GIS Environment

By Jane S. McColloch and Gayle H. McColloch, Jr.

West Virginia Geological and Economic Survey
1 Mont Chateau Road
Morgantown, WV 26508-8079
Telephone: (304) 594-2331
Fax: (304) 594-2575
email: *janemc@geosrv.wvnet.edu*, *mccolloch@geosrv.wvnet.edu*

Introduction

West Virginia Geological and Economic Survey (WVGES) has been collecting, archiving, and, more recently, developing digital databases of geologic and mineral resource data in West Virginia for many years. The extraction of petroleum resources in West Virginia began in 1859, and development of a digital oil and gas database at WVGES was initiated in the 1960s. Large-scale coal mining began in West Virginia immediately following the Civil War, and it has generated a wealth of coal resources and mining information. The Coal Bed Mapping Program (CBMP) and its predecessor the Coal Resources and Pollution Potential Study are sources of much pre-interpreted mineral resource information that has provided a starting point for our mapping. The structure of the Pittsburgh coal, shown in Figure 1, is an example of the large amount of coal resource information available at WVGES. Coal resource maps and GIS coverages have been created for 42 minable or potentially mineable coal beds in West Virginia. The WVGES Oil and Gas database, which contains information about more than 140,000 oil and gas wells, is another useful source of data. Locations of wells included in this digital database are shown in Figure 2. This information has enabled us to complete two or three quadrangles per year in data-dense areas. Even without this preprocessed information, given reasonable data density, the procedures described below represent a reasonable strategy to develop geologic maps in a GIS environment.

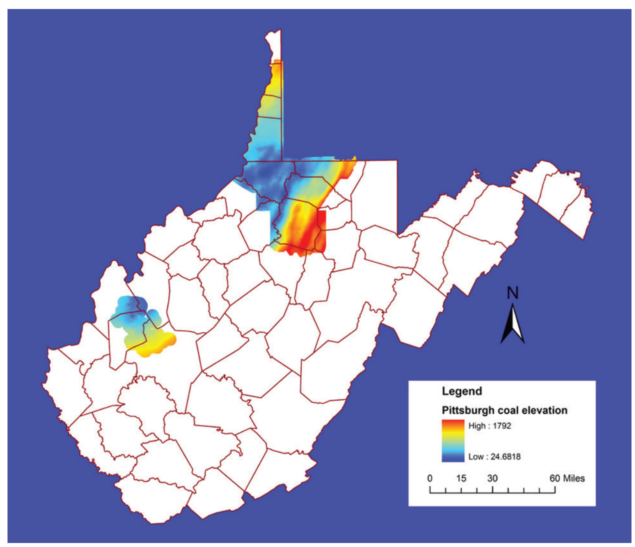


Figure 1. Structure of the Pittsburgh coal, which forms the base of the Upper Pennsylvanian Monongahela Group. The colors represent elevation of the base of the coal. Elevations range from less than 24 feet above sea level in the center of the basin (represented by the deepest blue) to 1792 feet above sea level (represented by the brightest red). Only those data from the minable extent of this coal are shown; the apparent gap in data in western West Virginia is because this coal is not economically minable there.

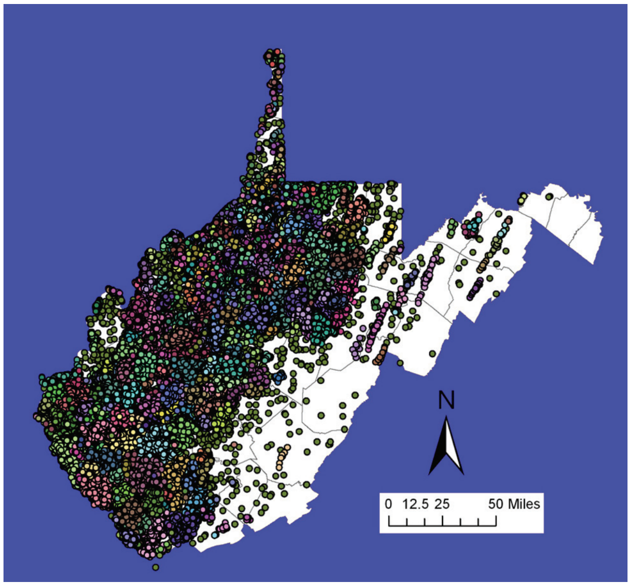


Figure 2. Locations of the more than 140,000 oil and gas wells contained in the WVGES Oil and Gas database.

Methodology

Geologic mapping in relatively flat-lying rocks of the Appalachian Plateau involves tracing important marker beds that are coals, sandstones, or other geographically extensive units. Pennsylvanian unit boundaries are frequently associated with coal beds. For example, the base of the Upper Pennsylvanian Monongahela Group is the base of the Pittsburgh coal bed (Figure 1) and the boundary between the Washington and Greene Formations of the transitional Upper Pennsylvanian-Lower Permian Dunkard Group is the base of the Jollytown coal bed (Figure 3).

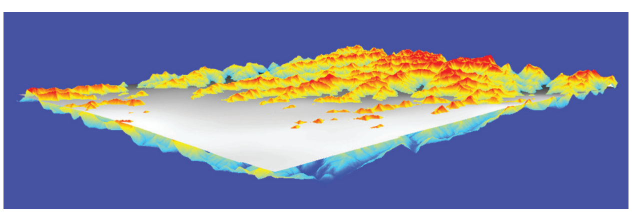


Figure 3. The Jollytown coal bed is the horizon that divides the Washington and Greene Formations of the transitional Upper Pennsylvanian-Permian Dunkard Group. The Jollytown coal bed structure on the Mannington 7.5-minute quadrangle is represented as the gray surface. This horizon was extrapolated above the underlying Washington coal bed by adding a fixed interval to the elevation grid. (A more sophisticated approach would be to record the interval at observation points and to compute the irregular surface.) The colored surface is the 1/9 arc-second-resolution digital elevation model; warm colors represent higher elevations and cooler colors represent lower elevations (vertical exaggeration is 3x). By definition, the cropline is the intersection of these two surfaces.

The first priority during a mapping project is to examine coal resources information produced by the CBMP and to identify gaps in data coverage where the important marker beds do not represent economically important resources. Oil and gas data, other data from WVGES files, and collection of additional field data are used to eliminate these gaps. Oil and gas data also provide subsurface information for improving the detail of cross sections.

Croplines of important beds are automatically generated by intersecting the grids representing structure of each bed with the grid representing the topography. This process is accomplished by subtracting the two grid surfaces and generating a zero contour line that denotes the cropline (Figure 3).

Preliminary field maps include the croplines of all critical horizons, as shown in Figure 4, which is a representation of part of the field map for the Mannington 7.5-minute quadrangle. In creating the preliminary field map, three-dimensional geologic data have in effect been reduced to two dimensions. After field maps are generated, the GIS-generated croplines are field checked to verify contacts. During the field check, additional field data are collected for our use and entered into field volumes and databases for future use.

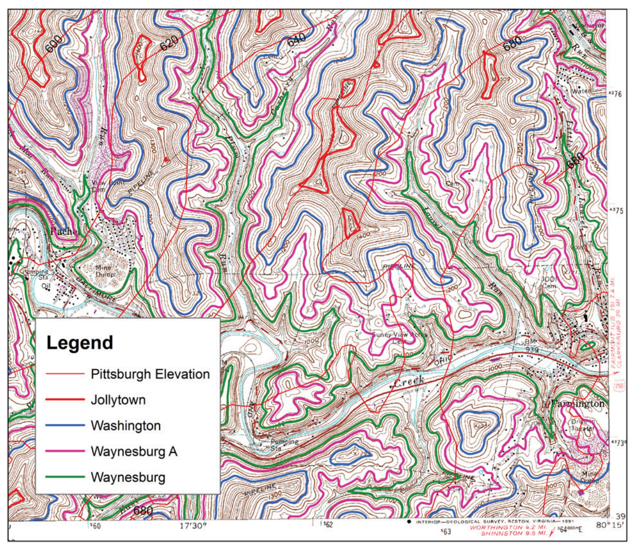


Figure 4. Part of the preliminary field map of the Mannington 7.5-minute quadrangle, showing croplines of critical horizons and the structure of the Pittsburgh coal that is thick and minable but does not cropout on the Mannington quadrangle.

After fieldwork is completed, the linework used to construct field maps is modified as needed, attributed, and built into final GIS datasets that are used to produce geologic maps (Figure 5). Cartalinx, an application produced by Clark Labs in Worchester, MA (*http://www.idrisi.com/products/cartalinx.cfm*), was used for editing, although other GIS editors could also be used. Cartalinx is our preferred editor because it is easy to use and it supports a version of the arc-node topology made popular by ArcInfo. This allows us to create outcrop

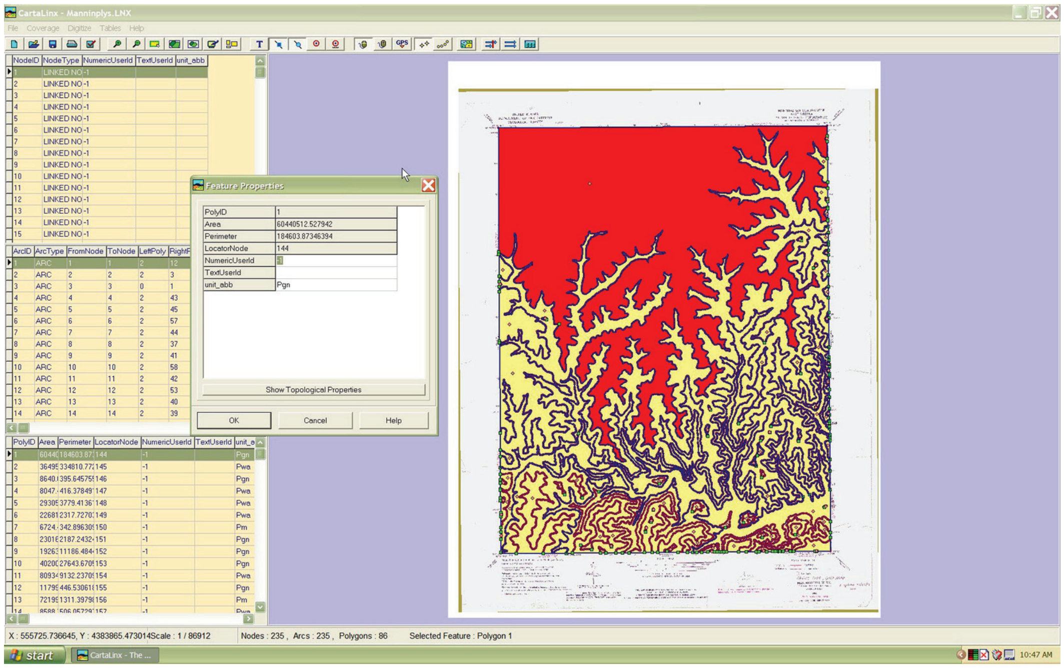


Figure 5. Cartalinx display of outcrop polygons on the Mannington 7.5-minute quadrangle.

lines that can be added to a coverage initially composed of a quadrangle border. The Cartalinx data model also supports distinct polygon locators that facilitate attributing the outcrop polygon coverage. The complete set of structure grids and the DEM enable the sampling of grids along profiles, and the sampled profiles are used to generate cross sections (Figure 6). Open-File Report maps are produced utilizing Adobe Illustrator with the MAPublisher plug-in (Figure 7).

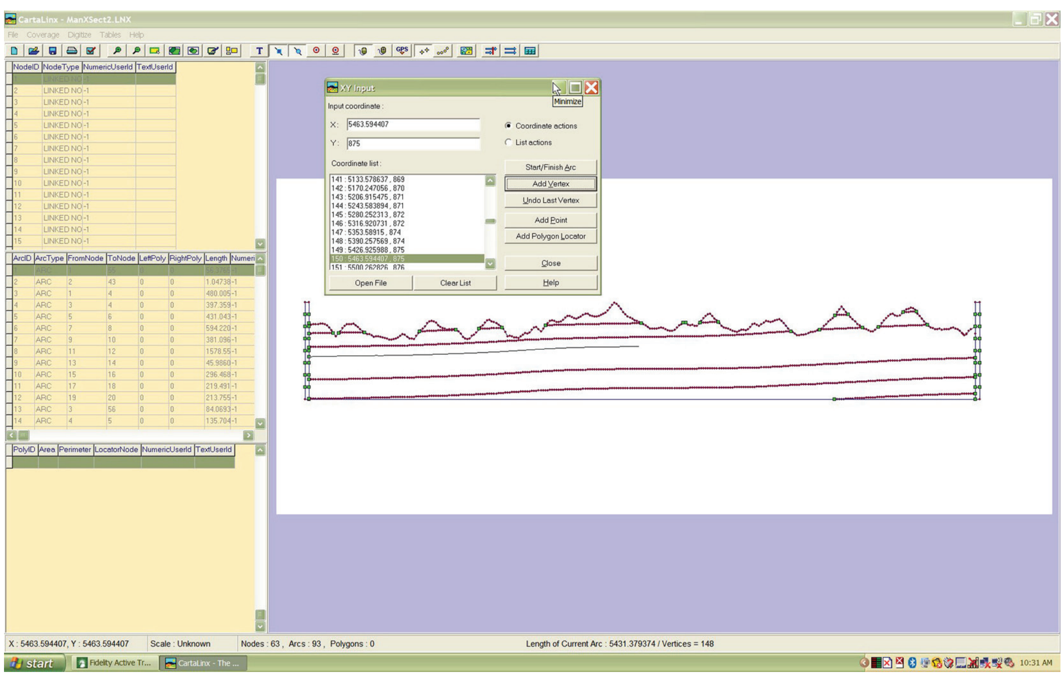


Figure 6. The cross section accompanying the preliminary geologic map of the Mannington 7.5-minute quadrangle is generated by sampling structure grids of critical horizons and the topographic grid along a profile. The incomplete line is in the process of being plotted using individual points from the elevation grid of the Waynesburg coal sampled along the cross-section line. The coordinates of the line being plotted can be seen in the window above the cross section in the illustration.

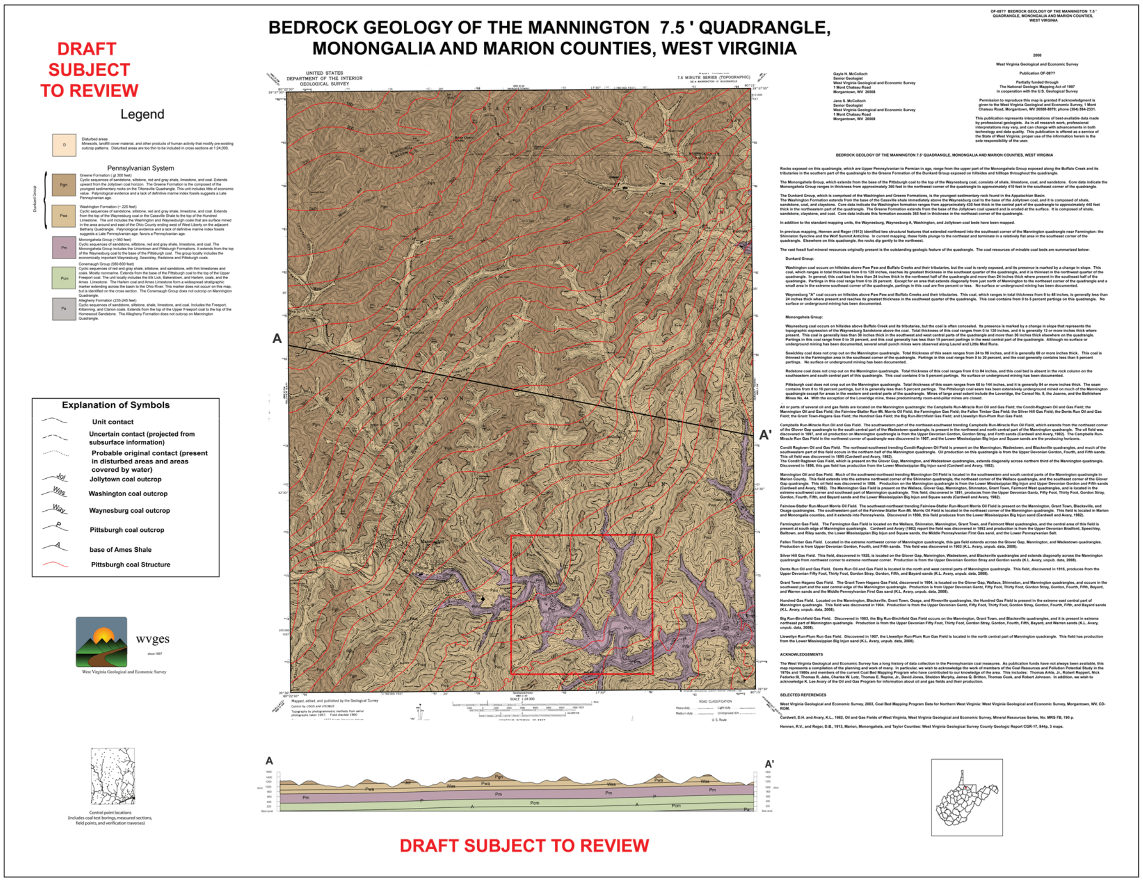


Figure 7. A reduced-size version of the open file Mannington 7.5-minute Geologic Quadrangle Map produced utilizing Adobe Illustrator with the MAPublisher plug-in.

Developing a New Base Map

A recent decision to produce a new West Virginia State Geologic Map has generated discussion of several issues including obtaining modern base maps for use in preparing new geologic maps of all scales.

The planned State Geologic Map is to be a living document representing the current state of knowledge about West Virginia geology. A robust data model and an accurate scalable base map are two tools that will make this possible. The North American Geologic Map Data Model Steering Committee has provided a suitable data model. Regarding the base map, the previous state geologic map (printed in 1968, with minor updates in 1986) uses the 1:250,000-scale Army Map Service 2-degree quadrangle series. A more suitable base map is being sought because this older series has a well-documented minor projection error (Snyder, 1987), it has become outdated, and there are no plans to produce an updated base at 1:250,000 scale. Ideally, the new base map would be a flexible statewide digital vector base, usable for scales ranging from 1:4800 to 1:250,000.

One possibility results from a data collection effort begun in 2003 when the West Virginia State Addressing and Mapping Board (SAMB) flew digital imagery of the state and subsequently made it available as state plane coordinate tiles (WVSAMB, 2004). In 2005, cooperative projects between the USGS, SAMB, and the West Virginia GIS Technical Center reformatted this imagery from state plane coordinates to digital orthophotoquads (DOQQs) (Figure 8) (USGS and WVSAMB, 2005) and produced 1/9 arc second digital elevation models (DEMs) (Figure 9) (USGS, 2005). In 2006, the West Virginia GIS Technical Center contoured the DEMs to produce a uniform statewide set of attributed shapefiles of 20-foot contours (WVGISTC, 2006). Figure 10 shows an unannotated base map of part of the Mannington 7.5-minute quadrangle that was produced using these contours and the new 2007 Census Bureau TIGER files (U.S. Census Bureau, 2007). In order to support the new West Virginia State Geologic Map, it will be necessary to first test whether current geologic mapping at 1:24,000 will fit the new base. Figure 11A shows part of the Mannington 7.5-Minute Geologic Quadrangle map that has a backdrop of scanned separates from the Mannington 7.5-minute topographic quadrangle produced in 1960 and photorevised in 1976. Figure 11B shows the same area using the linework from Figure 10 as a base map for comparison. Much additional testing will be necessary before a decision about this approach to a new base map is made, but this preliminary test is promising.

Figure 8. Digital orthophotoquad, with 2-foot resolution. The red box on Figure 7 delineates the area covered.

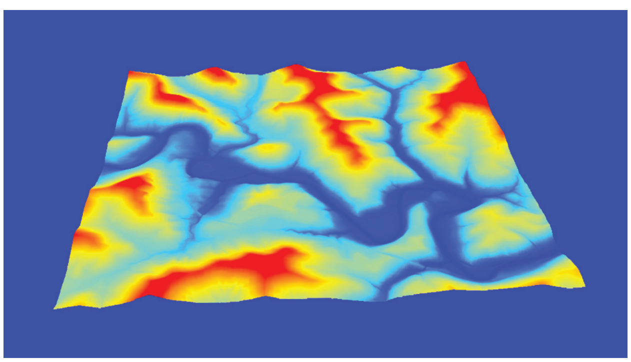


Figure 9. 1/9 arc-second Digital Elevation Model, produced from digital orthophotoquad imagery for area shown in Figure 8, looking north.

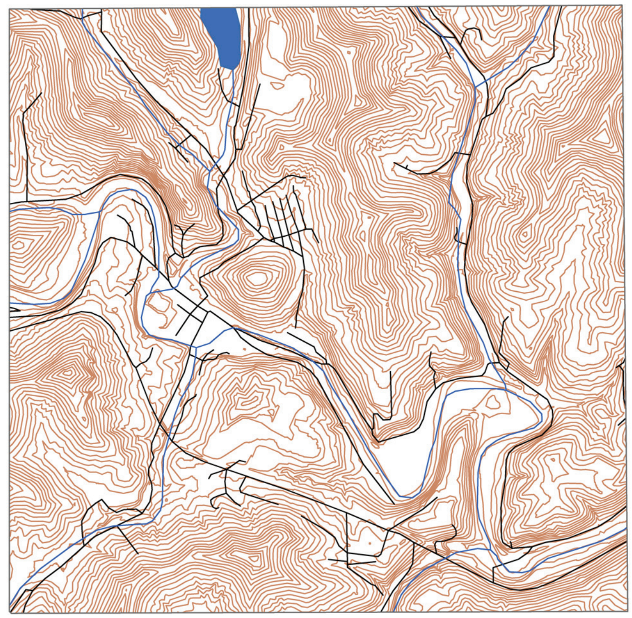


Figure 10. Twenty-foot contours produced from the DEM, and 2006 second edition Census Bureau TIGER files, used for a simplified unannotated base map.

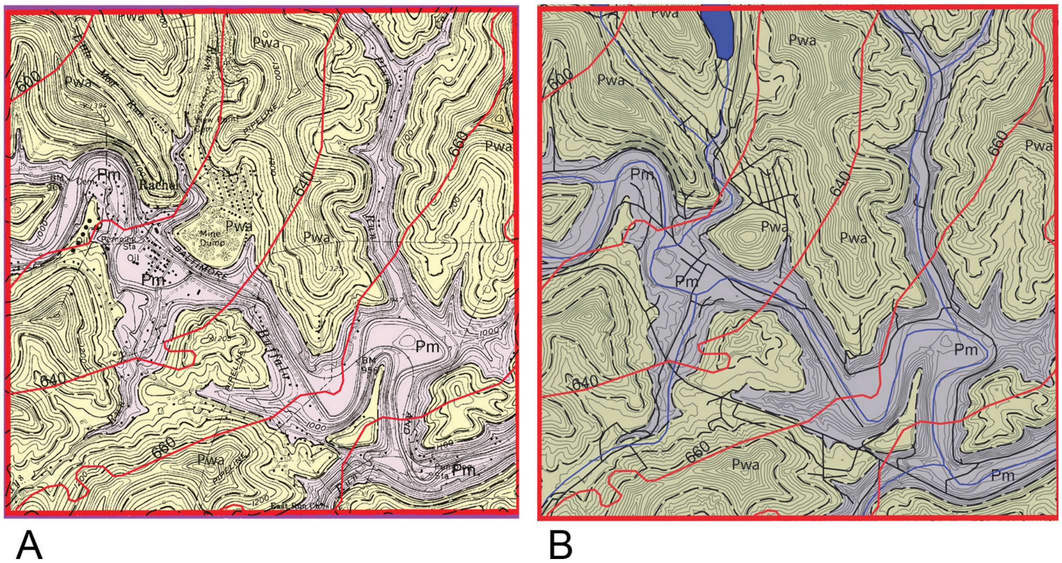


Figure 11. Mannington quadrangle geology at 1:24,000 from the draft open-file report, plotted on (A) scanned quadrangle separates and (B) the simplified base map shown in Figure 10.

References

Snyder, J.P., 1987, Map projections: A working manual: U.S. Geological Survey Professional Paper 1395, 383 p.

U.S. Census Bureau, 2007, 2006 Second edition TIGER/Line files, Washington, DC, U.S. Census Bureau, available at *http://www.census.gov/geo/www/tiger/tiger2006se/tgr2006se.html*.

U.S. Geological Survey (USGS), 2005, High Resolution 7.5' Quarter-quad orthoimages for the state of West Virginia, UTM Zone 17 for entire state, MrSID compressed: Sioux Falls, SD, U.S. Geological Survey, available at *http://wvgis.wvu.edu/data/dataset.php?action=search&ID=254*.

U.S. Geological Survey (USGS), and West Virginia Statewide Addressing and Mapping Board (WVSAMB), 2005, West Virginia statewide Digital Elevation Models: Rolla, MO, U.S. Geological Survey, available at *http://wvgis.wvu.edu/data/dataset.php?action=search&ID=261*.

West Virginia State Addressing and Mapping Board (WVSAMB), 2004, WVSAMB Color digital orthophotos: Charleston, WV, available at *http://wvgis.wvu.edu/data/dataset.php?action=search&ID=254*.

West Virginia University GIS Technical Center (WVGISTC), 2006, Elevation contours -20 feet: Morgantown, WV, West Virginia GIS Technical Center, available at *http://wvgis.wvu.edu/data/dataset.php?action=search&ID=264*.

Project Management GIS Applications and Tools for Coastal-Erosion Mapping in Ohio

By James McDonald

Ohio Department of Natural Resources
Division of Geological Survey
2045 Morse Road, Bldg. C-1
Columbus, OH 43229-6693
Telephone: (614) 265-6601
Fax: (614) 447-1918
email: *jim.mcdonald@dnr.state.oh.us*

Abstract

A major geologic hazard, coastal erosion along the Lake Erie coastline, jeopardizes the properties of Ohio landowners who live along the lake shore; many buildings and infrastructure are lost to coastal erosion. The State of Ohio has a program to map the coastal erosion areas (CEA) of the State every 10 years. The mapping of the CEA identifies areas at risk of being lost to coastal erosion within 30 years of the date of mapping. The CEA program informs owners of property that may be at risk and provides information on how to protect their properties from coastal erosion.

A number of geographic information system (GIS) applications and tools were created to assist with the conversion of the older, pre-digital CEA maps to a GIS. New GIS database forms recorded information on scanning of the maps and georeferencing of the scanned maps. An application was built to perform quality control checks of the georeferenced images and record the information into the GIS database. Another application loaded the georeferenced images into the map document, thereby speeding up access to individual images. Finally, an application was created that loads the control points of the georeferenced images into the GIS database. All of these applications have facilitated the task of converting older CEA maps into a GIS.

Introduction

Erosion along the Lake Erie shoreline of Ohio is a major geologic hazard that can significantly affect coastal residents. The coastline undergoes very dynamic large- and small-scale changes. Examples of large-scale changes are shown in Figures 1 and 2. Figure 1 shows a coastal area near Painesville, Ohio, that has undergone between 34 and 207 feet of recession from 1973 and 1990. Figure 2 shows the Sheldon Marsh barrier beach, which was blown out during the great November 1972 storm (Carter, 1973), and has undergone between 268 and 953 feet of recession during that 17-year period. While these large-scale changes are very dramatic, more normal erosion rates along the coast are also a hazard,

Figure 1. An area of the coast near Painesville, Ohio, that has undergone up to 207 feet of recession from 1973 to 1990. The figure shows the top of the bluff for 1876 (blue dashed line), 1973 (yellow dashed line), and 1990 (red dashed line), and also shows the parcels that have been lost due to coastal erosion since 1945. The black lines are the outlines of the parcels from the Lake County Auditor's Office. The base map image is from 2004.

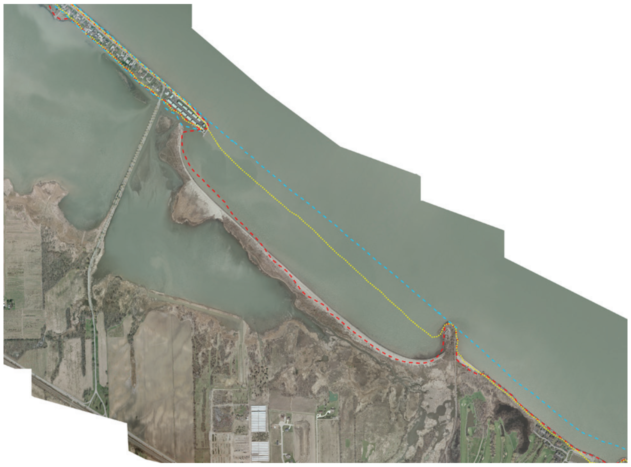


Figure 2. From 1973 to 1990, the Sheldon Marsh barrier beach has retreated at a rate between 15 to 56 feet per year (see Figure 1 for explanation of dashed lines).

eroding bluffs and destroying properties. For example, in Figure 3 a house is in danger of toppling because of erosion at the base of the bluff and rotational landslides that are caused by the unstable bluff slope. As a bluff recedes, buildings can be destroyed from the erosion, torn down before they are destroyed, or moved back from the bluff. Figure 4 shows three examples, including a 3,500 square foot house that was torn down and replaced some distance removed from the bluff.

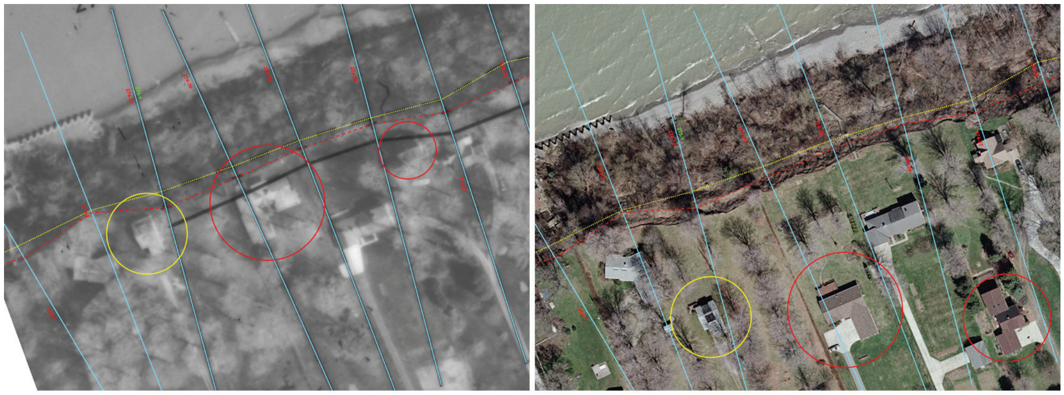
Figure 3. A home, circled in red, that is about to fall off of a bluff because of coastal erosion. Blue lines are shore-normal transects, as described in the text.

The geology, lake levels, prevailing winds, and shore protection affect coastal erosion rates. Between 1973 and 1990, the average shoreline recession was 1.41 feet per year, or approximately 23.92 feet over the 17-year time period. Recession rates along the coast range from 0 feet per year to up to 56 feet per year in certain areas of the coastline (see Figure 2).

Historically, 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 damages along Ohio's Lake Erie shoreline to be $11.3 million. The most significant storm of the twentieth 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 shoreline (Kriesel and Lichtkoppler, 1989; Kriesel and others, 1993). Many of the coastal properties in Ohio have structures close to the bluff edge. A study performed by the Lake Erie Geology Group of the Ohio Department of Natural Resources (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). All of these factors show that monitoring coastal erosion and informing the public about related hazards is an important on-going program.

The State of Ohio mandates that the CEA be designated for the Lake Erie coastline of the State every 10 years (Ohio Revised Code 1506.06). The mapping of the CEA identifies areas at risk of being lost to coastal erosion over a 30-year period. Once CEA areas are designated, the CEA program informs owners of property that may be at risk and provides them with information on how to protect their properties.

The first designation of the CEA was finalized in 1998. The 1998 CEA 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, 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 SigmaPlot software, with each 1990 aerial-photo image having its own relative coordinate system. Once digitized, the vector data was then used as input into a FORTRAN program that calculated the recession distance and recession rate between 1973 and 1990 and also calculated the 30-year average recession distance, i.e., where the shoreline is projected to be in 2020. The 30-year recession distance was then plotted back onto the 1990 imagery (Mackey and others, 1996; Guy, 1999). The preliminary CEA was released to the public in 1996. After public review and modifications to the preliminary CEA were completed, the final CEA was approved by the Director of the Department of Natural Resources in 1998.



A B

Figure 4. (A) 1990 aerial photo. The two homes circled in red will be either torn down or removed. The home circled in yellow will be moved back from the bluff edge. (B) 2004 aerial photo. The replacement homes are circled in red, and the home moved back from the bluff edge is circled in yellow.

GIS Project Management Software

The recent remapping of the CEA designation involved many different conversion and mapping steps within a GIS. One of the major steps to remap the CEA was to convert the older mylar photo maps and shoreline data to a GIS. There are 467 photographs from 1990 that cover Ohio's Lake Erie coast. The GIS conversion process of the 1998 CEA mylar images involved several tasks. First, the 1990 mylar aerial photos were scanned. Then, these images were georeferenced to the 2004 digital orthophotos, which are of higher accuracy. Quality control was then performed on the georeferenced images. Finally, the 1990 shore-normal transects, 1973 shoreline intercepts, and the 1990 shoreline intercepts were digitized from the 1990 mylar images.

In order to manage the conversion of the 1998 CEA mylar images to a GIS, a number of applications were created to assist with the project management, including applications for tracking the map-scanning tasks, georeferencing the images, and quality control of the georeferenced images. An attribute table tracked the various GIS tasks performed during the image scanning, georeferencing, and digitizing. Access to the attribute table is done using Visual Basic for Applications (VBA) forms and ESRI's ArcObjects within the ArcMap environment. Other applications were created to speed up the workflow of the GIS users. These applications included automating the loading of georeferenced images into ArcMap and managing the georeferenced control points. All of these applications were accessed by GIS users as buttons on a toolbar, which was named **CEA Tools**. Each of the applications helped track the tasks performed on each image and helped increase productivity, allowing the ODNR Division of Geological Survey to complete the task of converting the 1998 CEA images to a GIS.

CEA Scanning Information Form

The first step in the GIS conversion involved the scanning of the original mylar photos, upon which the shore-normal transects, the 1973 and 1990 shorelines, and the 1998 CEA designations were delineated. A VBA form using ESRI's ArcObjects was created for tracking the progress of scanning the mylar photos (Figure 5). The VBA form allows the recording of important information, namely, when the mylar photo was scanned, the operator who did the scanning, and when the image was transferred from the scanning computer to the network for storage. The information is recorded into the attribute table that tracks the various tasks as part of the GIS conversion project. The form in ArcMap is used primarily to view when the scanning took place and who performed the scanning.

To operate the form, the **CEA Scanning Information** application button is selected from the **CEA Tools** toolbar. Once the form has opened up in ArcMap, the user can select the 1990 photo-index name from the drop-down combo box. Once the photo-index name has been selected, information about the scanned image automatically is filled into the appropriate fields. At this point, the user can add or change any of the information associated with the scanned image. The information is recorded back into the database once the user selects the **Update** button.

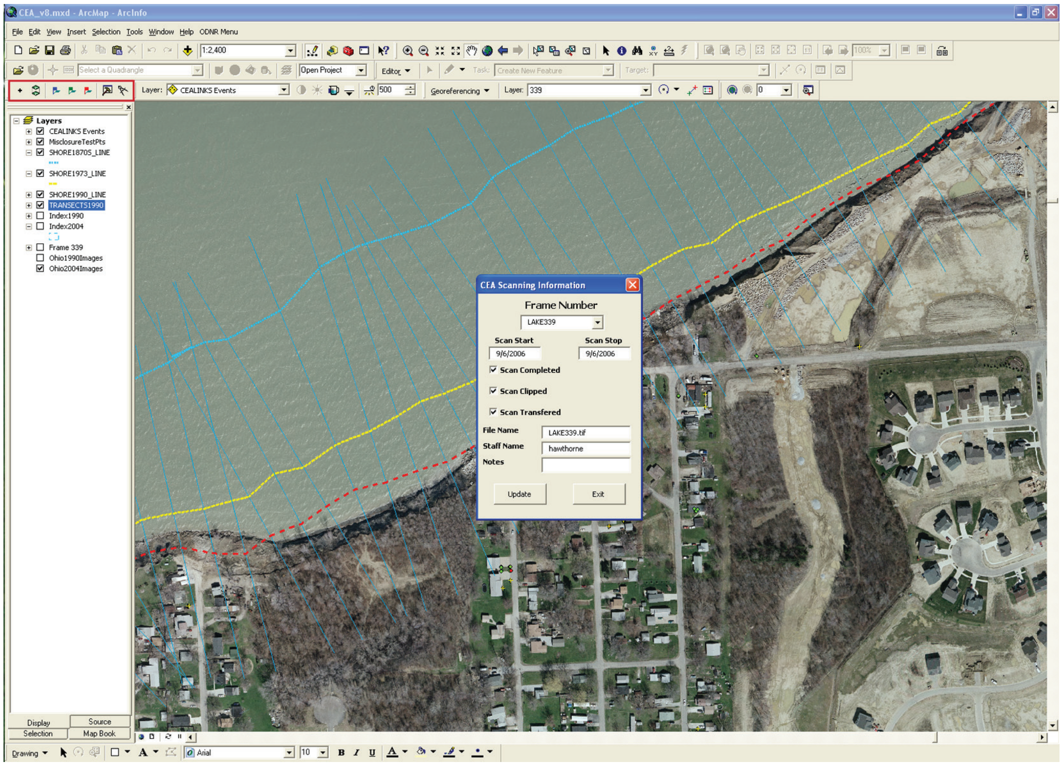


Figure 5 This VBA form tracks the progress of the mylar photo-scanning task. The **CEA Toolbar** is highlighted in red.

CEA Georeferencing Information Form

The next step in the GIS conversion involved georeferencing the raw images into the correct coordinate space. Another new application was created as a VBA form using ArcObjects to record and track the information associated with georeferencing the raw images (Figure 6). The form allows recording of information such as the date when georeferencing started and stopped; georeferencing parameters including the number of control points, the georeferencing order, and the RMS results; the name of the rectified file and its location; and the staff member who performed the georeferencing. All of this information is recorded in the attribute table that tracks the GIS project tasks.

To operate the form, the **CEA Georeferencing Information** application button is selected from the **CEA Tools** toolbar. Once the form has opened up in ArcMap, the user can select the 1990 photo-index name from the drop-down combo box. Once the photo-index name has been selected, the information about the georeferenced image automatically is filled into the appropriate fields. At this point, the user can add or change any of the information associated with the georeferenced image. The information is recorded back into the database once the user selects the **Update** button.

CEA Test Points Application

The standard technique for assessing the accuracy of an image involves measuring the misclosure distance of control points between a map or an image whose accuracy is being assessed and a map or an image of higher accuracy (Subcommittee for Base Cartographic Data, 1998). To perform this type of accuracy assessment on the georeferenced imagery, a tool was created that would allow accuracy points to be digitized and saved as a feature class in the geodatabase (Figure 7). The tool's main function is to calculate the misclosure distance between a test point on the newly created georeferenced image and a higher accuracy reference point. The misclosure is calculated and recorded as an attribute in the feature-class attribute table and the points are symbolized as to whether they pass or fail the quality control check.

To operate the application, the user first activates the **CEA Test Points** button on the **CEA Tools** toolbar. Once activated, a form opens within ArcMap. This form records and presents information about the quality control points that are digitized and presents a statistical summary of the overall accuracy of the georeferenced image. Next, the GIS user locates a well-defined feature that can be identified on both the 1990 and 2004 imagery. The user digitizes a point at

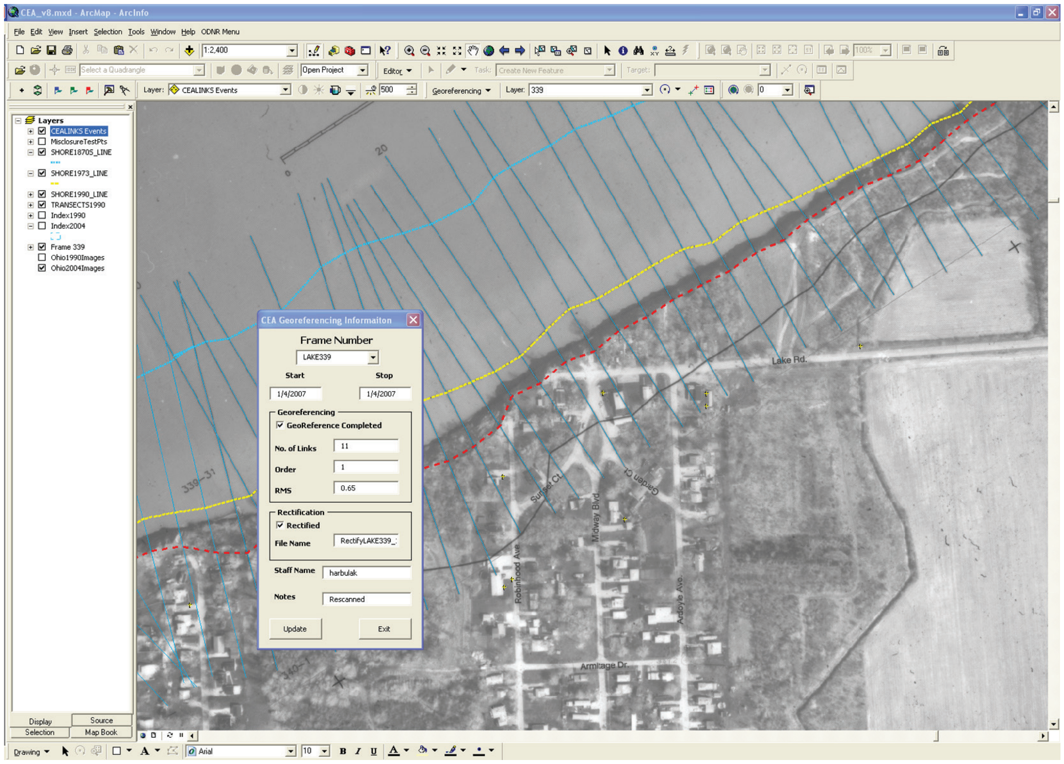


Figure 6. This VBA form tracks the progress of the mylar image-georeferencing task.

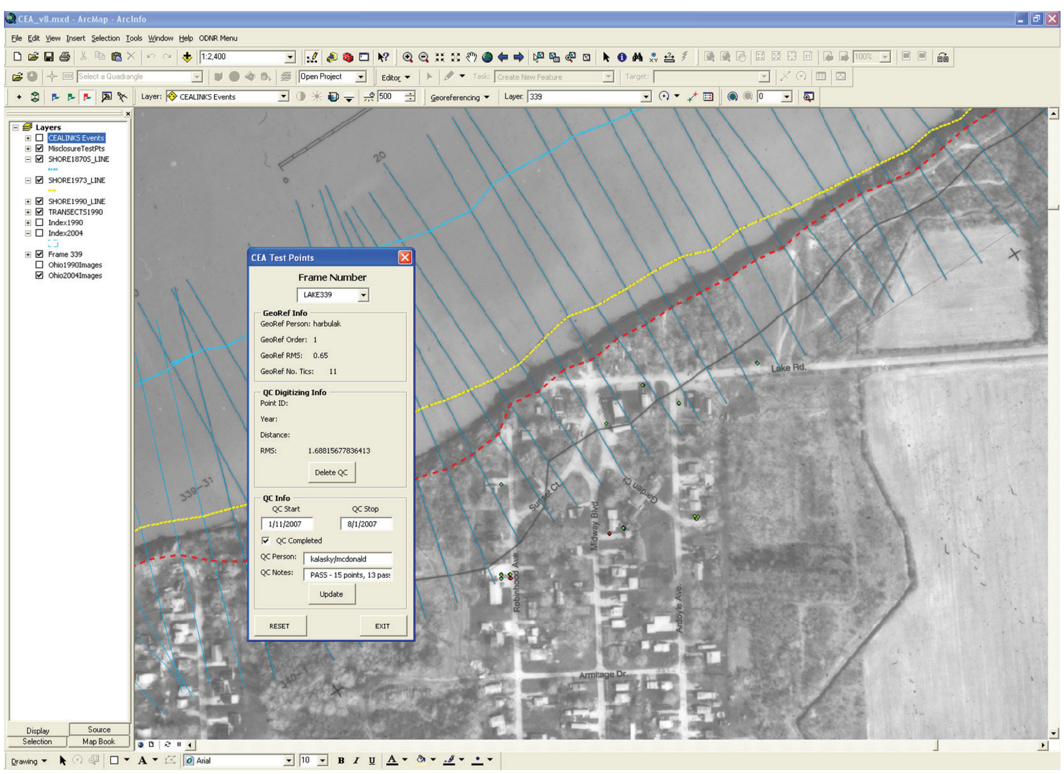


Figure 7 The **CEA Test Points** application provides a tool that allows test points to be digitized to check the accuracy of georeferencing.

the location of the well-defined feature on the 1990 imagery, turns off the display of the 1990 imagery, and then digitizes a point on the 2004 image. The application creates the two different points in the **MisclosureTestPts** feature class, calculates the distance, and calculates the summary statistics for the 1990 image. Using the summary statistics, the GIS user then can input comments about the relative accuracy of the georeferenced image. The GIS user performing the quality control assessment was also required to input their name in the **QC Person** input box to track the staff members that did the quality control on any particular image.

Load 1990 Imagery Application

An application was written to automatically load the desired 1990 and 2004 images into the GIS software (Figure 8). The application saves time because GIS users do not need to know the file names for the imagery nor the location of the imagery on the PC or the network. This particular application uses the index polygon feature classes for the 1990 imagery and the 2004 imagery to facilitate loading the imagery into ArcMap. When activated, the application searches for the selected polygon in the 1990-imagery index polygons and reads the 1990 photo-index name for the selected polygon from the attribute table. The application then performs an intersection of the selected 1990-imagery index polygon with the 2004-imagery index polygons. The application then reads and generates a list of 2004 photo-index names from the intersected polygons. The 1990 photo-index name and the list of the intersected 2004 photo-index names are then passed to Microsoft Scripting Runtime procedures that will search directories and subdirectories, find the 1990 and 2004 imagery associated with the index names, and load the imagery into ArcMap.

For the GIS user, the **Load 1990 Imagery** application is very easy to use. To operate the application, a GIS user selects the 1990 photo-index polygon, activates the application button on a toolbar, and then all of the images are loaded for that area. In addition, all of the images are grouped together in the ArcMap Table of Contents, and the group layer is placed at the bottom of the Table of Contents.

CEA Control Points Application

One of the project requirements was to save the georeferenced control points for each image as a text file. For the entire 1998 CEA conversion project, over 500 text files were created. The georeferenced control points files are managed using a new application (Figure 9). A VBA form was created that provides access to four different applications. The two buttons grouped together on the bottom of the form, **Load Frame** and **Load All**, will load the georeferenced control point text files into an attribute table in the GIS database. The attribute table is shown on the right side of Figure 9. Either a single text file can be loaded or an entire directory of georeferenced control point text files. Once loaded, the georeferenced control points can be displayed as an event feature class. Two other buttons, at the top of the VBA form, control the display of the georeferenced control points and the misclosure test points. When a 1990 photo-index frame is selected from the combo box and the **Frame** button is selected, ArcMap will zoom into the location of the selected 1990 image and hide all of the control points and misclosure

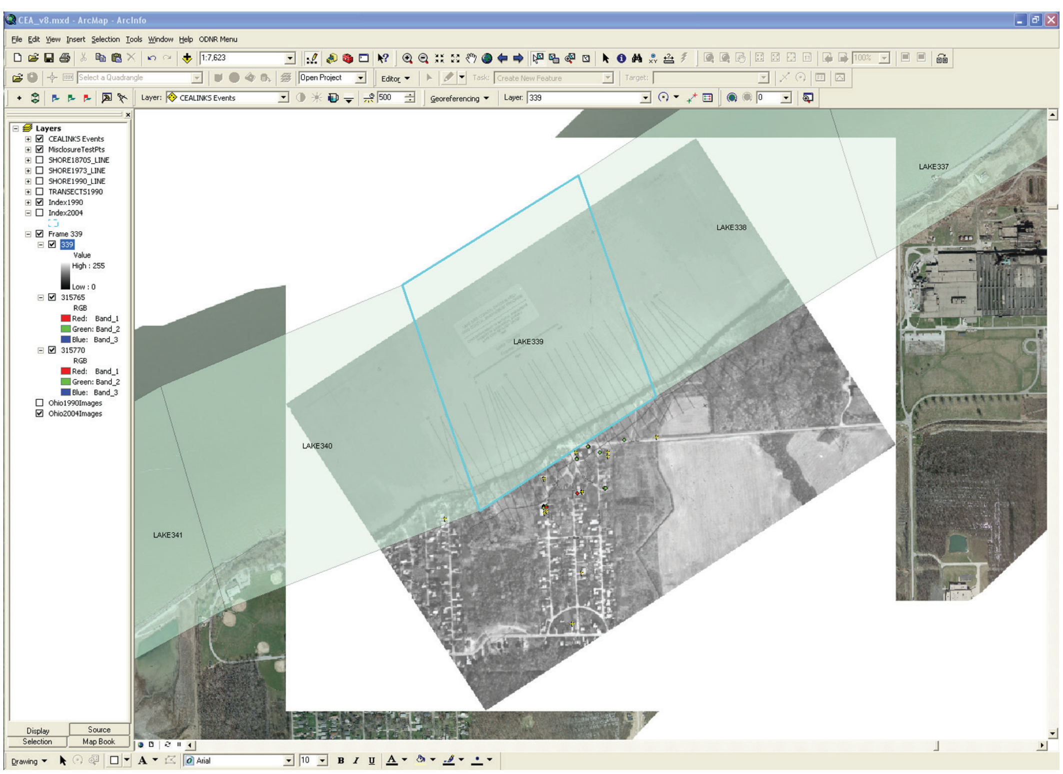


Figure 8. The **Load 1990 Imagery** application loads all of the 2004 images associated with the corresponding 1990 images. The figure shows the end result of loading the 1990 imagery to the ArcMap. The 1990 aerial-photo index polygon used to locate the 1990 image is highlighted in light blue; the 1990 aerial-photo image (gray-scale image) is loaded beneath the 1990-index polygon, and beneath the 1990 aerial photo image is the 2004 color imagery.

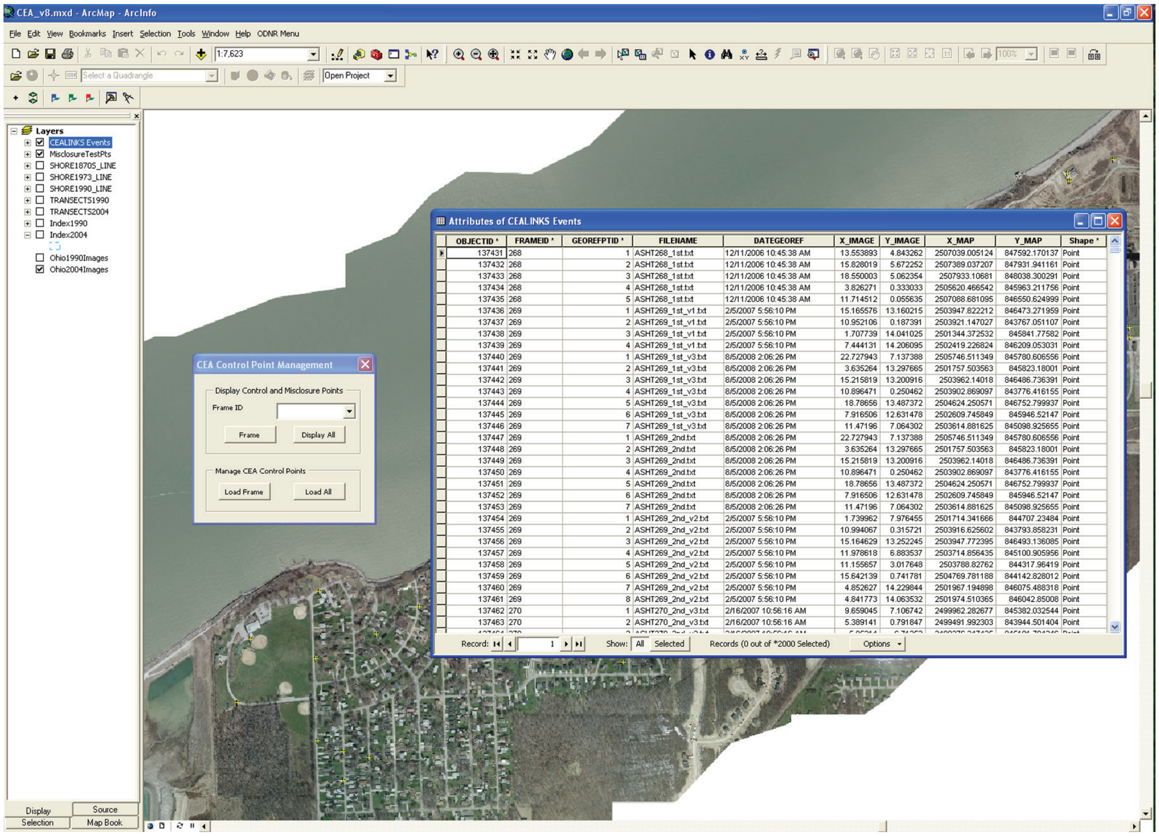


Figure 9. The CEA Control Points application manages the georeferenced control points in the GIS.

points not associated with the selected image. The application applies a definition query to both the georeferenced control points and the misclosure points, which allows the GIS user to only examine the georeferenced control points and misclosure points for a single image. The other button, **Display All**, will zoom out to the entire extent of the data and display all the points by removing the definition query.

Conclusions

Each of these new tools allowed for better project management during the course of the 1990 CEA conversion project. The ODNR Division of Geological Survey had two separate offices working on georeferencing the mylar images. While five student interns and two staff members worked in the Columbus office, two staff members were located in the Sandusky, Ohio, office, more than 100 miles away. Consequently, managing the work load, assigning tasks and data to people, and tracking the disposition of the data and the progress of the tasks was a challenging endeavor. Only by using these tools were we able to track all the images, files, and tasks without losing data or losing track of the assigned tasks.

Acknowledgments

I would like to thank staff members Paul Harbulak, Connie Livchak, and Donovan Powers, and student interns Emily Foley, Chris Gordon, Tim Hawthorne, Natalie Kalasky, and Joe Marulli for their assistance in completing this project.

References

Carter, C.H., 1973, The November 1972 storm on Lake Erie: Ohio Department of Natural Resources, Division of Geological Survey Information Circular 39, 12 p.

Environmental Data Service, 1972, Storm data: U.S. Department of Commerce, NOAA, v. 14, no. 11, p. 178–185.

Guy, D.E., Jr., 1999, Erosion hazard area mapping, Lake County, Ohio: Journal of Coastal Research, Special issue 28, p. 185–196.

Kriesel, Warren, and Lichtkoppler, Frank, 1989, Coastal erosion and the residential property market: Columbus, Ohio, Ohio Sea Grant Fact Sheet 044 and appendix, 6 p.

Kriesel, Warren, Randall, Alan, and Lichtkoppler, Frank, 1993, Estimating the benefits of shore erosion protection in Ohio's Lake Erie housing market: Water Resources Research, v. 29, p. 795–801.

Mackey, S.D., Foye, D.A., and Guy, D.E., Jr., 1996, Lake Erie recession-line mapping—An update, *in* Folger, D.W., ed., Lake Erie Coastal Erosion Study Workshop, 4th annual, St. Petersburg, FL, April 16–18, 1996, Proceedings: U.S. Geological Survey Open-File Report 96-507, p. 37–39.

Subcommittee for Base Cartographic Data, 1998, Geospatial Positioning Accuracy Standards, Part 3—National Standard for Spatial Data Accuracy: Federal Geographic Data Committee, 28 p., accessed at *http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3*.

U.S. Army Corps of Engineers, 1971, National Shoreline Study—Great Lakes Inventory Report: Chicago, Department of the Army, 221 p.

Geologic Content Specification for a Single-Map Database

By Stephen M. Richard[1] and David R. Soller[2]

[1] Arizona Geological Survey / U.S. Geological Survey
416 W. Congress #100
Tucson, AZ 85701
Telephone: (520) 770-3500
Fax: (520) 770-3505
email: *steve.richard@azgs.az.gov*

[2] U.S. Geological Survey
926A National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6977
email: *drsoller@usgs.gov*

Introduction

The design of geoscientific database systems for use by geological surveys presents a special set of challenges. In contrast to application-specific designs that are driven by a particular use case, geological survey systems need to allow for the wide variety of data typically collected, and for the possibility of new projects demanding new types of content. The published and unpublished information archive function of most geological surveys establishes a need to record the source and update history of that information. Because users have widely varying needs and technical capabilities, a simple and easily understood data structure is most practical, because the budgets of most surveys do not provide a level of funding necessary to implement and support sophisticated, or multiple, data management systems. The geological survey community has long recognized the potential benefits of a standardized database platform to enable savings by sharing tools, training, and documentation costs. Several approaches to developing a community database schema for geoscience information have been defined and evaluated in the past 15 years. These include a relational database design (e.g., "v.4.3" of Johnson and others, 1998), a conceptual model ("NADM C1" of NADMSC, 2004), and numerous other database designs by various agencies involved in geologic map production, documented to varying degrees and related to each other in various ways. No consensus design has emerged.

The U.S. National Geologic Map Database project (NGMDB, *http://ngmdb.usgs.gov/*) has participated in this development and testing of database designs and has test-implemented a complex enterprise database design based on the NADM C1 model (Richard and others, 2004). In light of comments made above, we are continuing to work toward a relational database schema that achieves a functional balance between simple design and ability of the data structure to accurately represent some of the complex relationships inherent in geoscience information. Our objective is to develop a database that is primarily useful for delivering a single dataset (e.g., a publishable geologic map), thereby providing a moderate level of functionality that will be useful for data interchange.

Some Proposed Designs

We have surveyed a variety of logical designs that have been proposed or used over the years for geoscience databases (see Selected References). These range from a simple flat-file data structure to complex, highly normalized relational (database) or network (XML) schema. Based on the common geoscience entities in these schemes, we have developed a content specification that we propose as the basis for a geoscience delivery database.

Except for simple, single flat-file designs, all the designs involve a link from a spatial object (point, line, or polygon) to one or more descriptive entities that are collections of properties, and some scheme for associating the spatial objects with symbols for portrayal. There is some variation in the logical structure for associating the spatial objects with multiple descriptions, for associating descriptions with classes or instances, and for the amount of location, observation method, and confidence metadata associated with the spatial object location and classification.

Given that the various logical models are broadly compatible, the major challenge to developing a basis for information interoperability is to agree on the content model or specification for the kinds of information that should be included in a geoscience database. The NADM C1 conceptual model is a content model, but it uses Unified Modeling Language (UML) terminology that is unfamiliar to many geoscientists. The CGI Interoperability Working Group (Commission for the Management and Application of Geoscience Information (CGI), a commission of the International Union of Geological Sciences (IUGS)) built on the NADM C1 model to develop an XML markup schema for geoscience information (*https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/GeoSciML*). The GeoSciML XML schema is currently being tested and implemented by various geological surveys. This paper is a distillation of these various geoscience data models to outline a broadly applicable content specification for a geoscience database.

Content Specification

A content specification is a listing of the kinds of information that need to be represented in a table, an XML element, or an entire database. The content specification informs users on the information content of a resource and helps software designers to understand the scope and requirements of tools that will be used to maintain or access the resource.

In the simple content specification presented here, principal geoscientific and cartographic elements are described. It is basically a conceptual model expressed in natural language. More detailed and proscriptive specifications are necessary to allow development of software that would access the design. Those specifications would be based on this simple content model. The content specification we outline here has three potential applications:

1. Facilitating data interchange – A shared data schema for transferring packages of geoscience information, but not visualization, for input into automated processing pipelines that use geoscience data, or for publishing data in an implementation-independent format. Because the design anticipates automated processing, it requires a very proscriptive specification, e.g. XML schema and controlled vocabularies from a registry.
2. Off-the-shelf package for geoscience GIS – A geodatabase against which standard tools could be developed for automating geologic map data (e.g., ArcGIS extension), and to facilitate the use of maps as an aid for inputting observation data. This would be most useful for agencies that are not already using a geodatabase-based approach, or are new to GIS. This application would need topology rules to assist line and polygon editing, and domains to usefully restrict user input to minimize errors in data entry. For the long term, tools to simplify construction of the map collar legend and symbolization scheme would be feasible.
3. Map viewing– A mechanism for packaging a complete map layout (e.g., the cartography) along with the associated data. The spatial objects must have a simple linkage to symbols used to depict them. Mechanisms for implementing transport of actual graphic objects (e.g., ArcMap layer, ArcView legend file, OCG styled layer descriptor file) are out of scope but would be necessary for a working system.

Proposal for Geologic Map Dataset Content

The content listed here is a summary of the content related to a typical geologic map publication. Each agency or community would need to evaluate the importance of these different content elements to determine if they should be optional or required for information interchange.

Geologic Units

Geologic units are identifiable, mappable parts of the Earth (North American Geologic-Map Data Model Steering Committee, 2004). A geologic unit description may be associated with a unit distinguished by a particular symbol (color) on a geologic map (a map unit), or with a subset of polygons assigned to a map unit in order to describe variations in that unit, or with individual observation locations and associated raw field data. Suggested content is listed below. Table 1 contains a supplementary list of properties associated with geologic units in the GeoSciML model, as examples of other more detailed information that might be included.

- Stratigraphic Unit – association of a mapped unit with some formal nomenclature scheme.
- Lithologic composition – representation of the composition of a geologic unit in terms of the kinds of rocks that form the unit.
- Preferred age – assignment of a single geologic age, chosen to be most representative of the mapped unit. The age specification can be numeric or based on named eras from a stratigraphic time scale.

- History of unit (sequence of events) – a sequence of events in the formation of the mapped unit. The preferred age will be the age of one of these events.
- Geomorphic character – the Earth surface expression of the mapped unit.
- Symbolization – association of the mapped unit with a graphical element for the purpose of map display.
- Metadata – information documenting the provenance of the geologic unit description.
- Thickness – thickness of the mapped unit, may be reported as a single value or a range.

Marker Beds

Marker beds are a kind of geologic unit included in the North American Code of Stratigraphic Nomenclature as the lowest-level unit. Marker beds that are not unit boundaries do not participate in the topology, but are always contained within some other stratigraphic unit of which they are a part.

Geologic Structures

A geologic structure is a configuration of matter in the Earth based on describable inhomogeneity, pattern, or fracture (North American Geologic-Map Data Model Steering Committee, 2004). A geologic structure description may be associated with one to many individual features. Suggested content is listed below. Table 2 contains a supplementary list of properties associated with geologic structures in the GeoSciML model, as examples of other more detailed information that might be included.

- Type or category classifier – association of the mapped feature with some category that describes the geologic nature of the feature.
- Preferred age – assignment of a single geologic age, chosen to be most representative of the geologic structure. The age specification can be numeric or based on named eras from a stratigraphic time scale.
- History (sequence of events) – a sequence of events in the formation of the structure. The preferred age will be the age of one of these events. For faults, this property would include the slip history across the fault.
- Orientation – for a planar or linear structure, geologists are interested in the orientation of the feature in an earth-surface reference frame, typically relative to a horizontal surface with azimuth measured relative to north.
- Symbolization – association of a graphical element with the structure, for purposes of map display.
- Metadata – information documenting the process by which the structure was located, who mapped the feature, and less often, the context in which the feature was mapped.

Fold-Hinge Surface Traces

In terranes with map-scale folds, the traces of hinge surfaces commonly are mapped to help elucidate the geometry and location of the folds. These surfaces are based on the orientation of bedding or the curvature of traceable folded surfaces such as marker beds or contacts between units.

Table 1. Selected list of additional properties associated with geologic units, from the GeoSciML specification.

Bedding pattern	Magnetic susceptibility	Porosity
Bedding style	Metamorphic facies	Unit thickness
Bedding thickness	Metamorphic grade	Weathering degree
Body morphology	Outcrop character	Weathering process
Composition category	Peak pressure value	Weathering product
Contained structure	Peak temperature value	Weathering environment
Density	Permeability	
Exposure color	Protolith rock type	

Table 2. Selected list of additional properties associated with geologic structure descriptions, from the GeoSciML specification.

amplitude	hingeLineCurvature	profileType
axialSurfaceOrientation	hingeLineOrientation	segment
boundedGeologicUnit	hingeShape	spacing
contactCharacter	intensity	span
continuity	interLimbAngle	symmetry
definingElement	layerComposition	totalDisplacement
foldSystemMember	limbShape	wavelength
geneticModel	mineralElement	
higherOrderFoldPart	periodicity	

Dikes and Veins

Dikes and veins are sheet-like bodies of intruded rock, which are generally too thin to represent as polygons. Dikes and veins may have multiple disconnected instances (e.g., outcrops), unified by their lithologic character and relationship to other units. Dikes and veins are intruded along fractures, and thus have a structural aspect as well. Although they may intrude along contacts or faults, dikes and veins generally are independent of the topology of surfaces bounding the principal geologic units in an area.

Observation Points

Field data that are the basis for compiling geologic maps generally are acquired through observations collected at point locations, which then are extrapolated to define the map geometry. Point observations may be associated with map unit descriptions, structure descriptions, or samples. The observation points and original, detailed descriptive data typically are not included directly in a map interpretation, but are important to store in geoscience databases because they document the fundamental observational basis for the interpretations represented on a map.

Sample Locations

Physical samples collected in the field are referenced to their geologic setting by specifying the location at which they were collected, possibly along with more detailed observation data of relationships between the sampled material and the surrounding rock and structure at the sample location.

Cartographic Points

The geologic map includes numerous annotation items that could be located by points in the map layout. These include graphical symbols that encode arrows showing fault dip direction, bar and ball or other symbols that encode fault slip or separation sense, symbols used to indicate the kind of fold closure observed along a mapped hinge surface trace, numbers to indicate magnitude of dip or plunge of structures, map unit labels, or generalized, representative measurements of strike and dip for planar structures such as bedding. These are called cartographic points because their location may be determined by graphical and esthetic considerations, in order to best communicate some aspect of the geologic information in a particular map portrayal. In ESRI Geodatabase language, these would be included in one or more annotation feature classes, which include a bounding box geometry and encode the graphical element in an opaque 'blob' field. A more transparent (but less flexible and functional) approach is to include one or more point feature classes to locate structure symbols, label text for polygons, and label text for inclination values of structure data in a map layout.

Spatial Data and Database Feature Classes

Because geologic features are located in the Earth, a fundamental content requirement for any geoscience database is the ability to accurately represent locations in the Earth. Current geographic information system software is designed to represent and manipulate descriptions of location. Two-dimensional systems typically allow representation of points, lines (ordered collections of points), and polygons (collections of lines that form closed rings). It is anticipated that in the future these systems will operate in three dimensions as well, and the feature types will expand to include volumes.

Geoscience features are associated with spatial objects in order to place them in a geographic context. One of the basic design decisions that must be made in any geologic spatial database is the mapping between geoscience features and database feature classes. The term "feature class" is used here to mean a representation entity (e.g., a table in a database, an element in an XML document) that has a location property. Criteria affecting the feature class design include entity typing based on properties associated with the entity, and the relationships between entities that are built into the representation schema to enable various use cases for the database implementation (e.g., digitizing and editing, data archive, quality assurance, cartographic design). At a conceptual or logical level, it is common to try to preserve a correspondence between the feature classes and geoscientific entities. For physical implementations, pragmatic design criteria become of primary importance. These include ease of implementation and use, and constraints that may be determined by the specific GIS software environment.

In general, points in geoscience geographic databases locate observations or sample collections, or more rarely they represent geologic features that are too small to represent with an extended geometry (line, polygon) at the scale of representation. Lines locate the intersection of planar geologic features with the map horizon represented by the map portrayal. Thus, lines typically are associated with contacts between units, faults, dikes, veins, and marker beds. Lines also may represent geologic features that are inherently linear, such as scarp crests, dune crests, channel axes, or fold hinges in a particular folded surface. Polygons represent patches within which a mapped unit is found on the map horizon. Typically the mapped unit is a rock volume, and the polygon represents the intersection of a three-dimensional body with the map horizon. Less commonly, the polygon may represent a unit defined by the character of the outcrop surface. The specific partitioning of these representations into different feature classes is outside the scope of this specification.

Conclusions

Design of a widely useful community geoscience database schema depends on careful consideration of the purpose of the schema, and scoping of the content to balance simplicity against depth of scientific representation. The specification presented here is based on comparison of existing database implementations as a means of identifying content that is commonly included in actual datasets. This sort of ‘bottom-up’ approach has become increasingly useful as more geoscience databases have been implemented and populated, and provides an instructive counterpoint to the more ‘top-down’ design processes that have dominated proposals for standardized schemas.

Selected References

Bain, K.A. and Giles, J.R.A., 1997, A standard model for storage of geologic map data: Computers and Geosciences v. 23, p. 613-620.

Brodaric, B., Journeay, M., Talwar, S., and others, June 18, 1999, CordLink Digital Library Geologic Map Data Model Version 5.2: Geological Survey of Canada unpublished report, accessed at *http://cordlink.gsc.nrcan.gc.ca/cordlink1/info_pages/English/dm52.pdf*, accessed June 13, 2001.

Brodaric, Boyan, and Hastings, Jordan, 2002, An object model for geologic map information, *in* Richardson, D., and van Oosterom, P., eds., Advances in Spatial Data Handling, 10th International Symposium on Spatial Data Handling: Heidelberg, Germany, Springer-Verlag, p. 55-68.

Gautier, D.L., 1999, Data model for single geologic maps: An application of the national geologic map data model, *in* Soller, D.R., ed., Digital Mapping Techniques ’99—Workshop Proceedings: U.S. Geological Survey Open-File Report 99-386, p. 77-81, *http://pubs.usgs.gov/of/1999/of99-386/gautier.html*.

Harris, Carl F.T., 1998, Washington State’s 1:100,000–scale geologic map database: An ArcInfo data model example, *in* Soller, D.R., ed., Digital Mapping Techniques ‘98—Workshop Proceedings, U.S. Geological Survey Open–File Report 98–487, p. 27–35, *http://pubs.usgs.gov/openfile/of98–487/harris.html*.

Hastings, J.T., Raines, G.L., and Moyer, L.A., 2008, Proposal for an ArcGeology Version 1 – A geodatabase design for digital geologic maps using ArcGIS, *in* Soller, D.R., ed., Digital Mapping Techniques ‘07—Workshop Proceedings: U.S. Geological Survey Open-File Report 2008-1385, p. 59-72, *http://pubs.usgs.gov/of/2008/1385/pdf/hastings.pdf*.

Johnson, B.R., Brodaric, B., and Raines, G.L., 1998, Digital Geologic Maps Data Model, V. 4.3: unpublished report, accessed at *http://www.nadm-geo.org/dmdt/*.

Lewis, R.S., Burmester, R.F., Kauffman, J.D., and Frost, T.P., compilers, 2001, Digital geologic map of the St. Maries 30 x 60 minute quadrangle, Idaho: Idaho Geological Survey, Digital Geologic Map 1, version 2.2002.06.

North American Geologic-Map Data Model Steering Committee, 2004, NADM Conceptual Model 1.0, A conceptual model for geologic map information: U.S. Geological Survey Open-File Report 04-1334, 61 p., *http://pubs.usgs.gov/of/2004/1334/*.

O’Meara, S.A., and Poole, A.R., 2004, National Park Service Geologic Resources Inventory Geology–GIS coverage shapefile data model: unpublished report, 107 p., accessed at *http://www1.nature.nps.gov/im/gis/GeologyGISDataModel.htm*.

O’Meara, S.A., Stanton, H.I., Chappell, Jim, and others, 2005-2007, NPS GRI Geology-GIS Geodatabase Data Model (V. 1.1 to 1.4): unpublished report, 147 p., accessed at *http://www1.nature.nps.gov/im/gis/GeologyGISDataModel.htm*.

Richard, S.M., 2006, Geoscience Concept Models, *in* Sinha, Krishna, ed., Geoinformatics-Data to knowledge: Geological Society of America Special Paper 397, p. 81-108.

Richard, S.M., 2003, Geologic map database implementation in the ESRI Geodatabase environment, *in* Soller, David R., ed., Digital Mapping Techniques '03—Workshop Proceedings: U.S. Geological Survey Open-File Report 03-471, p. 169-183, *http://pubs.usgs.gov/of/2003/of03-471/richard2/index.html*.

Richard, S.M., and Orr, T.R., 2001, Data structure for the Arizona Geological Survey Geologic Information System – Basic geologic map data, *in* Soller, David R., ed., Digital Mapping Techniques '01—Workshop Proceedings: U.S. Geological Survey Open-File Report 01-223, p. 167-188, *http://pubs.usgs.gov/of/2001/of01-223/richard2.html*.

Richard, S.M., Craigue, J., and Soller, D.R., 2004, Implementing NADM C1 for the National Geologic Map Database, *in* Soller, D.R., ed., Digital Mapping Techniques '04—Workshop Proceedings: U.S. Geological Survey Open-File Report 2004-1451, p. 111-144, *http://pubs.usgs.gov/of/2004/1451/pdf/richard.pdf*.

Richard, S.M., and CGI Interoperability Working Group, 2007, GeoSciML – a GML application for geoscience information interchange, *in* Soller, D.R., ed., Digital Mapping Techniques '06—Workshop Proceedings, U.S. Geological Survey Open-File Report 2007-1285, p. 47-59, *http://pubs.usgs.gov/of/2007/1285/pdf/Richard.pdf*.

Soller, D.R., Brodaric, Boyan, Hastings, J.T., Wahl, Ron, and Weisenfluh, G.A., 2002, The central Kentucky prototype: An object-oriented geologic map data model for the National Geologic Map Database: U.S. Geological Survey Open-File Report 02-202, 39 p., *http://pubs.usgs.gov/of/2002/of02-202/*.

Sharing Technical Information with Nontechnical Users—An Example from the Monterey Bay Area Quaternary Fault Atlas

By Lewis I. Rosenberg

Tierra Geoscience
P.O. Box 1693
Tijeras, NM 87059
Telephone: (505) 384-1010
email: *tierrageoscience@gmail.com*

Introduction

One of the critical issues in geoscience is to effectively communicate information to a target audience. Even more difficult is to communicate the same information to more than one audience. This paper presents a case history of designing earthquake fault maps to be easily understood by geoscientists as well as by nontechnical users.

Situated approximately 150 kilometers (km) south of San Francisco, the project study area is subject to significant earthquake hazards. Several active faults cross the Monterey Bay area, including the well-known San Andreas Fault and Hayward Fault, as well as the lesser known but also hazardous Calaveras Fault and San Gregorio Fault (Figure 1). California law prohibits constructing buildings across Holocene-active (about 11,000 years or younger) faults. However, existing maps showing these faults are commonly at different scales (typically 1:24,000 to 1:100,000) and different vintages (1970s to 2000s). Hence, local governments do not always have access to accurate, recently published fault maps, even in paper format, on which to base their land-use decisions.

Engineering geologists investigate the presence of faults and their recency of movement by digging trenches across the faults using backhoes and creating a descriptive log of the subsurface conditions. The geologist's reports are submitted

Figure 1. Map showing location of study area and active faults.

to local government as part of the land-use permit process. However, not all government agencies keep or catalog these fault studies. Having access to previous fault studies is a valuable asset in targeting areas where additional studies are needed. Digitally storing fault studies is one way to accomplish the archiving of these valuable records.

The purpose of this study was to compile fault maps and trench logs for the faults within areas that have been active during the Quaternary (from about 1.8 million years ago to the present day). Two grants from the U.S. Geological Survey's National Earthquake Hazard Reduction Program (NEHRP) funded this study. Although much of the NEHRP-funded research is extremely useful to geologists and seismologists, the findings are commonly written in language that is unfamiliar to the layperson. An important goal of NEHRP is to provide information that nontechnical users can understand, in order to help them reduce their exposure to earthquake hazards. Thus, one of the goals of this study was to provide a method of communicating complex geoscience information to laypeople as well as to scientists.

NEHRP also requires that products be in some type of digital format. Owing to the large study area (nearly 12,400 km^2), the map design presented some challenging issues. For example, even though the map was a digital product, many users absorb the information more effectively from traditional paper maps, or at least seem to prefer this medium. Ideally, the data could be designed with a micro/macro composition to help users visualize both the details and the "big picture" (Tufte, 1990). Oversize map sheets initially were considered, but the constraint of needing several sheets to cover the study area made that concept unsuitable. An atlas format using 8½ × 11 inch sheets had the advantage of presenting detailed data, but lacks the regional perspective.

On the other hand, a strictly digital map satisfies the ability to zoom in for a detailed perspective and to zoom out for a regional perspective. However, one of the barriers to acceptance of digital maps is the cost of software and learning the program needed to view and query the map. For example, it is not obvious that ESRI shapefiles are a collection of three to seven related files, not just the .shp file itself. This misunderstanding can cause difficulty in using GIS files. For these reasons, the data from this study were published as Keyhole Markup (KML) files, in addition to shapefiles. The advantage of this dual-format approach is that there are many more users familiar with Google Earth software (which uses KML files) than the more specialized ESRI software.

Nontechnical users can easily view fault locations and exploratory trench locations with Google Earth, or with Web browsers using the Google Maps or the Virtual Earth viewers. They can also combine these data with other information, such as house locations provided by their real estate agent. Thus, presenting the information in KML format helps the non-technical user to reduce their risk from earthquake hazards by providing a familiar approach to help them recognize active faults in relation to their property.

The KML file for this study contains low-resolution thumbnail images of the fault trench logs. Hyperlinks to high-resolution scans of the trench logs are also included. The low- and high-resolution images are stored remotely on a server where they can be downloaded from anywhere. This approach has the advantage of providing users with a relatively small KML file.

Building the KML File

There are several methods that can be used to build KML files. One method involves working with software through the Internet ("cloud computing") and utilizes an online spreadsheet program, Spreadsheet Mapper, developed by Google for ease in creating KML files. The spreadsheet is preformatted, with the user filling the blank cells with latitude, longitude, and descriptions. The advantage of Spreadsheet Mapper is that it allows collaboration with other locations; so more than one geologist or cartographer can work on the same project from anywhere. The disadvantage is that only point data can be created with Spreadsheet Mapper. Lines and polygons need to be created with other software. An example of the spreadsheet is shown on Figure 2.

The trench data were exported from ArcGIS files into Microsoft Excel spreadsheet files that contained the site coordinates, the site name, the geologic consultant, and URL links for the low- and high-resolution map and trench log images. The data from the Excel files were cut and pasted into

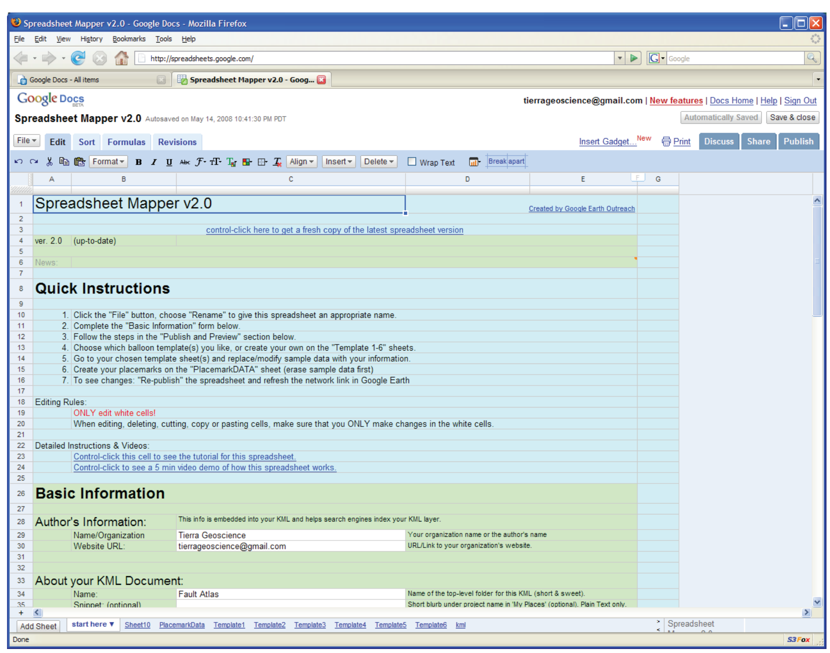


Figure 2. Screenshot showing Google Spreadsheet Mapper.

Spreadsheet Mapper. There are also several preformatted "bubble" templates in Spreadsheet Mapper, which display descriptive information when an icon in Google Earth is selected. The format and content of the bubbles can be modified using a text editor or commercially available HTML creation software.

Another technique for building KML files is to use the "Layer To KML" toolbox in ArcGIS 9.3, which creates a KMZ file (a compressed KML file) for point, polyline, and polygon features. This method has the advantage of being simpler, but the trade-off is less flexibility in displaying the results. The default ArcGIS information display in Google Earth is a table-style balloon (Figure 3). Commercial software such as "Arc2Earth," provides additional capabilities in creating KML files, such as formatting bubbles, utilizing ArcGIS renderers (Unique Value, Class Breaks), exporting three-dimensional shapefiles, and exporting KML files directly to Web servers such as Amazon S3.

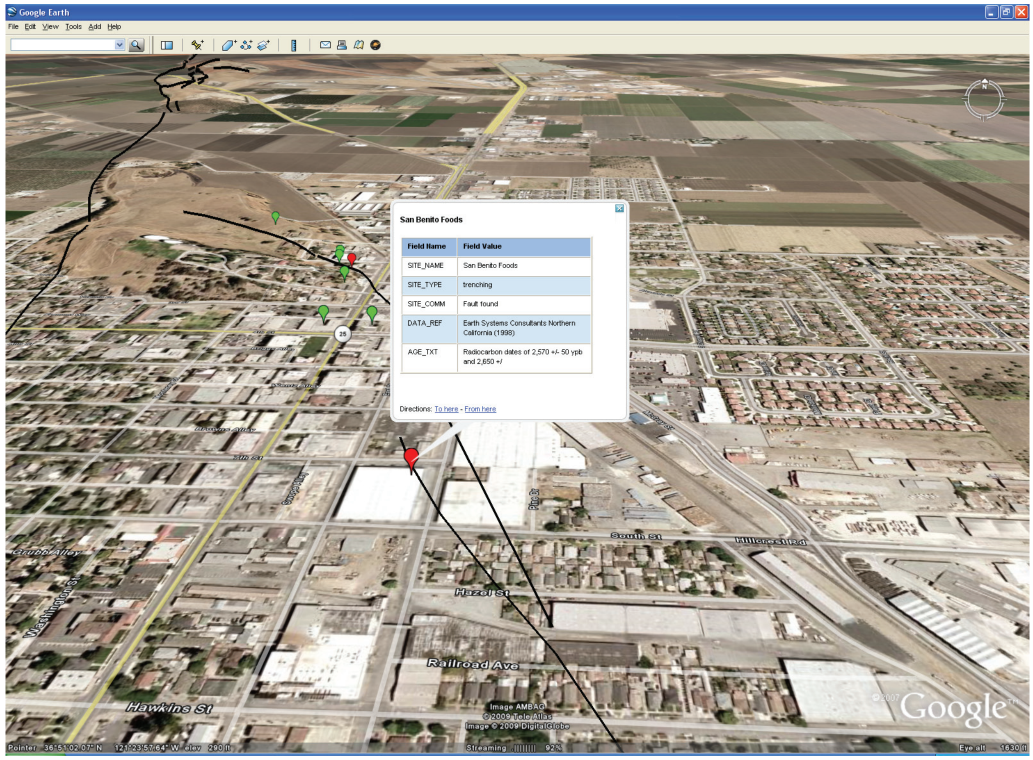


Figure 3. Screenshot of Google Earth Web interface showing Quaternary fault traces (solid black lines), location of fault trenches where fault was found (red teardrops), location of fault trenches where fault was not found (green teardrops), and summarized information (in bubble).

Storing Data on Amazon S3

Files for this study are stored on the Amazon Simple Storage Service, commonly referred to as Amazon S3. The advantage of using Amazon S3 is that the data are stored on servers that are accessible worldwide, are scalable, and are encrypted. The current (2009) cost for storing data is relatively inexpensive with rates of $0.15 per GB per month for the first 50 TB of storage used, $0.10 per GB for all data loaded to the server, and $0.17 per GB per month for the first 10 TB of data downloaded by users.

However, Amazon does not include a front-end interface for their Amazon S3. One solution is the freeware S3Fox Organizer plug-in for Mozilla's Firefox Web browser. As shown in Figure 4, S3Fox Organizer provides a graphical interface to move files to and from Amazon S3. One nice feature of the Arc2Earth software is the ability to directly export KMZ files to Amazon S3 within the ArcGIS environment (Figure 5).

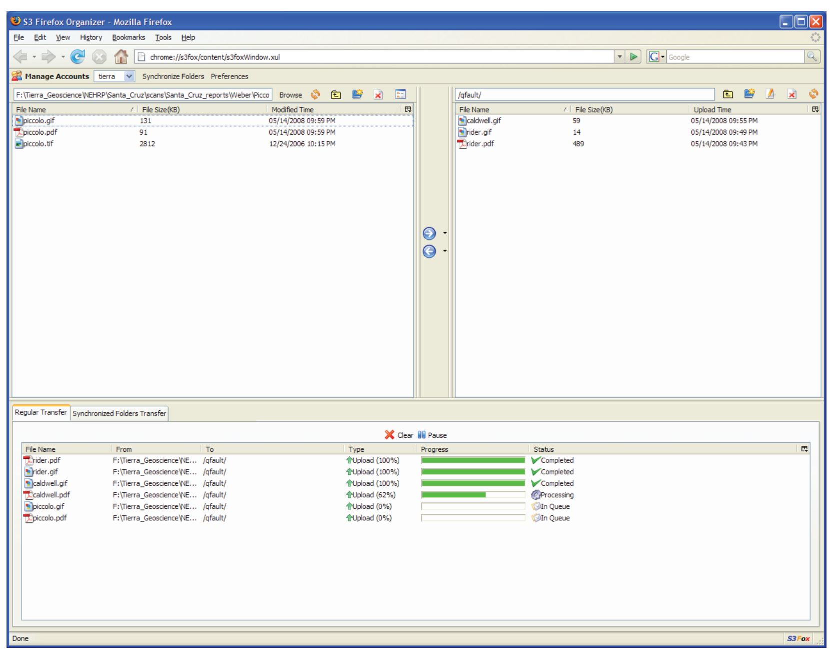


Figure 4. Screenshot showing S3Fox Organizer file management interface to the Amazon S3 server.

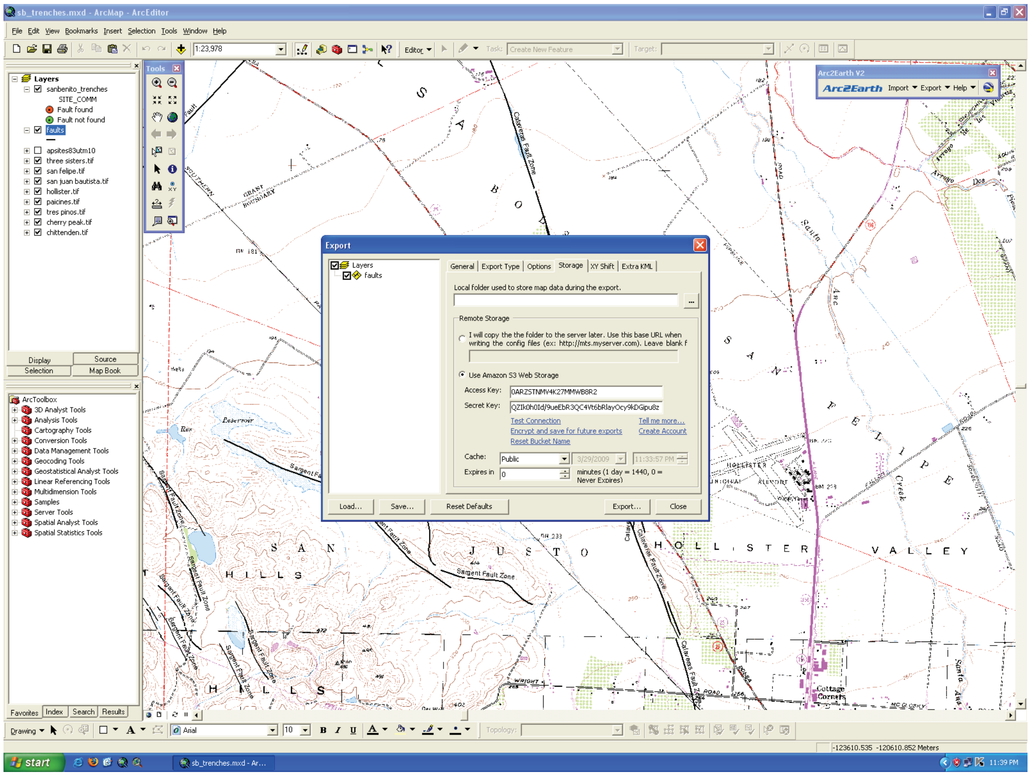


Figure 5. Screenshot showing Arc2Earth export from ArcGIS to Amazon S3 server.

Viewing and Downloading Data

The resulting KML and KMZ files can be displayed in Google Earth, in Google Maps, and in Microsoft Virtual Earth or other software capable of reading KML and KMZ files. Other advantages of using this approach include the ability to combine the fault trenching sites and fault layers with features such as parcel boundaries and roads.

Images of fault trench logs and site maps are stored as files on Amazon S3 and accessed from URL hyperlinks shown in the Google Earth information bubble for each fault trench site. The ArcGIS files for this study are also stored on Amazon S3, with a URL providing access to the data. This method has the advantage of being easier, faster, and less expensive than supplying the files on a CD. It also facilitates having the most current version of the database available to users.

The approach of using Spreadsheet Mapper, Amazon S3, and Google Earth also has potentially useful application in many geologic mapping projects, especially for post-natural disaster mapping. The collaborative nature of Spreadsheet Mapper combined with the distributed storage of Amazon S3 could be valuable for their ease of use, rapid sharing of data, and resistance to data loss from computer servers in the affected areas. However, there is the potential issue for Web servers to go out of business, so it is advisable to retain backups of all files. In addition, there are possible privacy issues for cloud computing, especially for sensitive or proprietary data. As this technology matures, the cloud computing applications will likely become more common and the uses for collaborative spreadsheets and distributed storage will become more widespread among geologists and cartographers.

Acknowledgments

Research was supported by the USGS, under USGS award numbers 05HQGR0016 and 06HQGR0017 to Lewis I. Rosenberg (Tierra Geoscience) and Joseph C. Clark. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government or by Tierra Geoscience.

Special thanks to Dave Soller for his continual encouragement and for reviewing this paper. As always, his comments and suggestions were useful.

Reference

Tufte, E.R., 1990, Envisioning information: Cheshire, CT, Graphics Press, 126 p.

Vendor Contact Information

Amazon S3—Amazon.com, 1516 2nd Ave., Seattle, WA 98101 USA, (800) 201-7575, *http://aws.amazon.com/s3*.

Arc2Earth—Arc2Earth LLC, 270 Davidson Ave., Suite 301, Somerset, NJ 08873 USA, *http://www.arc2earth.com*.

ArcGIS—Environmental Systems Research Institute (ESRI), Inc., 380 New York St., Redlands, CA 92373-8100 USA, (909) 793-2853, *http://www.esri.com*.

Firefox—Mozilla, 1981 Landings Drive, Building K, Mountain View, CA 94043 USA, *http://en-us.www.mozilla.com/en-US/firefox*.

Google Earth—Google Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043 USA, (650) 253-0000, *http://earth.google.com*.

Google Maps—Google Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043 USA, (650) 253-0000, *http://maps.google.com*.

Microsoft Excel—Microsoft Corp., One Microsoft Way, Redmond, WA, 98052 USA, (425) 882-8080, *http://office.microsoft.com/en-us/excel/default.aspx*.

S3Fox Organizer—Suchi Software, *http://www.s3fox.net*.

Spreadsheet Mapper—Google Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043 USA, (650) 253-0000, *http://spreadsheets.google.com*.

Washington Geological Survey GIS Statewide Landslide Database—From Design to Implementation

By Isabelle Y. Sarikhan and Kelsay M.D. Stanton

Washington Department of Natural Resources
Division of Geology and Earth Resources
P.O. Box 47007
Olympia, WA 98504-7007
Telephone: (360) 902-1450
Fax: (360) 902-1785
email: *isabelle.sarikhan@dnr.wa.gov*

Introduction

The Department of Natural Resources, Geology and Earth Resources Division (DGER), also known as the Washington Geological Survey, actively identifies, assesses, and maps geologic hazards using modern geotechnical and geophysical methods. Our hazard maps are critical for land-use and emergency-management planning, disaster response, and building-code amendments. As our population grows, there is increasing pressure to develop in hazardous areas; thus, delineating these areas is imperative. In response to the Washington State Growth Management Act's mandate to use the 'best available science,' our geologists meet with local governments and citizens in at-risk communities to educate about geologic hazards and ensure these hazards are taken into account when planning for growth management and for disasters. The DGER is also a first responder to natural disasters, helping to staff the State Emergency Operations Center at Camp Murray and documenting damage in the field. Besides volcanic and earthquake hazards, Washington is also prone to landslides triggered by intense rainfall or earthquakes. Landslides kill more people and cost more overall each year than other natural disasters combined (Bell, 1999). Nationally, landslides account for over 2 billion dollars of loss annually and result in an estimated 25 to 50 deaths a year (Schuster, 1996; Spiker and Gori, 2000; Schuster and Highland, 2001). Additionally, according to Washington State legislative mandate RCW 43.92.

> *" . . . the geological survey must conduct and maintain an assessment of seismic, landslide, and tsunami hazards in Washington. This assessment must include the identification and mapping of volcanic, seismic, landslide, and tsunami hazards, an estimation of potential consequences, and the likelihood of occurrence. The maintenance of this assessment must include technical assistance to state and local government agencies on the proper interpretation and application of the results of this assessment."*

DGER has designed and is implementing a GIS-based, statewide landslide database at both 24K and 100K scales (Figure 1), which is accessible on our ArcIMS site for download as an Arc Coverage file located at *http://wigm.dnr.wa.gov/*.

Data Assembly

Over many years, various landslide databases have been created in different divisions of the Washington Department of Natural Resources (DNR) to meet a variety of purposes. In 1999, the Division of Forest Practices created the first GIS statewide inventory of landslides (Boyd and Vaugeois, 2003). This database incorporated previously mapped landslides of all scales. The DGER has been involved in various projects, from mapping landslide hazards in Cowlitz County in response to the Aldercrest-Banyon landslide, to hazard response such as the Nisqually earthquake in 2001 and the December 3, 2007, storm that caused significant landslide-related damage. However, each of these datasets and databases was intended to meet particular goals. The statewide database includes an assessment of the reliability of database entries and uses the appropriate attributes from these previous databases, with a notation indicating where the data were obtained. An additional database is linked to the statewide database to provide information on the economic impact of landslides when the data are available. This secondary database is intended for mitigation and development planning purposes.

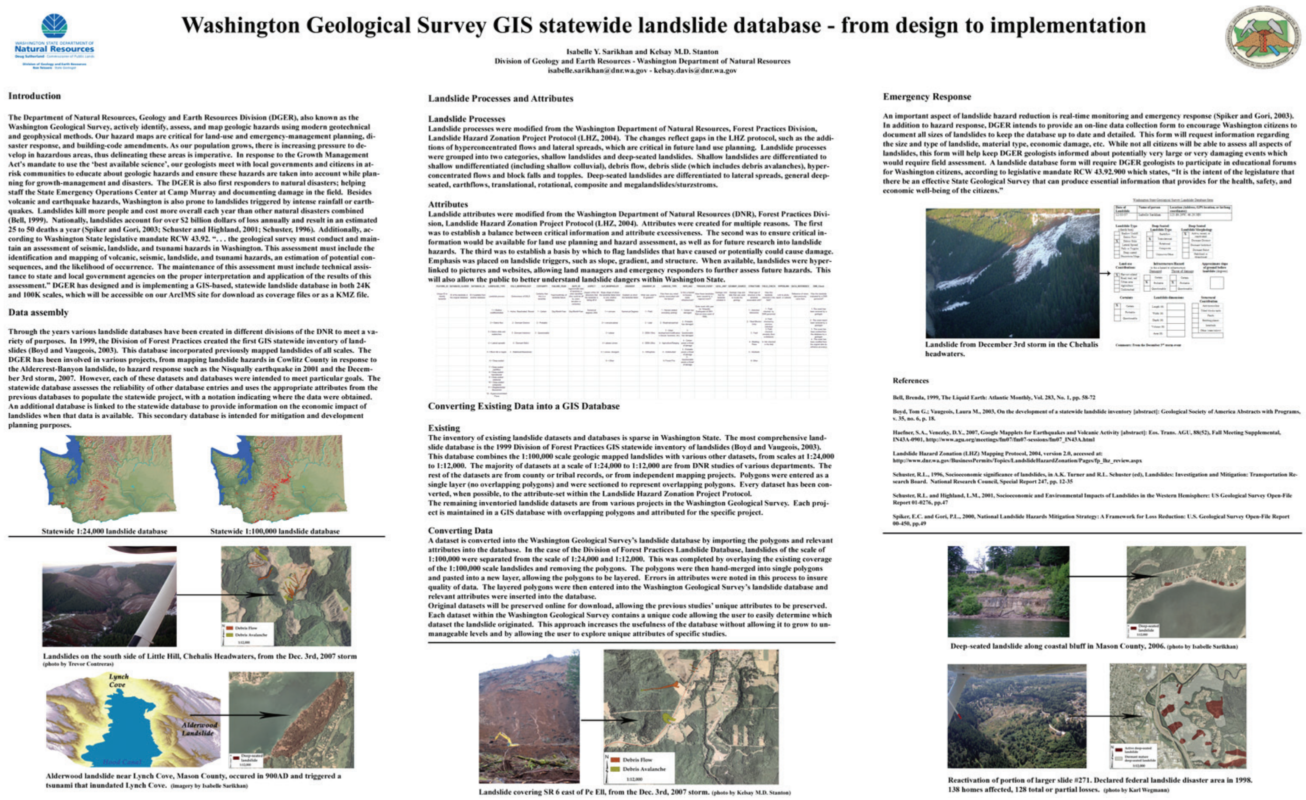


Figure 1. Page-size version of DMT'08 poster showing the DGER statewide landslide database (see full-resolution image at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_Sarikhan.pdf*).

Landslide Processes and Attributes

Landslide Processes

The classification of landslide processes was modified from the Washington Department of Natural Resources, Forest Practices Division, Landslide Hazard Zonation (LHZ) Project Protocol (Washington State Department of Natural Resources, 2004). The changes reflect gaps in the LHZ protocol, such as the additions of hyperconcentrated flows and lateral spreads, which are critical in land use planning. Landslide processes were grouped into two categories, shallow landslides and deep-seated landslides. Shallow landslides are classified as shallow undifferentiated (including shallow colluvial), debris flow, debris slide (which includes debris avalanches), hyperconcentrated flows and block falls, and topples. Deep-seated landslides are classified as lateral spreads, general deep-seated, earthflows, translational, rotational, composite, and mega-landslides/sturzstroms.

Attributes

The types of landslide attributes were modified from the Landslide Hazard Zonation (LHZ) Project Protocol (Washington State Department of Natural Resources, 2004). Attributes were created for multiple reasons. The first was to establish a balance between recording the critical information and defining an excessive number of attributes. The second was to ensure critical information would be available for land use planning and hazard assessment, as well as for future research into landslide hazards. The third was to establish a basis by which to identify landslides that have caused or potentially could cause damage. Emphasis was placed on landslide triggers, such as slope, gradient, and structure. When available, landslides were hyperlinked to pictures and websites, allowing land managers and emergency responders to further assess future hazards. This will also allow the public to better understand landslide dangers within Washington State.

Converting Existing Data into a GIS Database

The inventory of existing landslide datasets and databases is sparse in Washington State. The most comprehensive landslide database is the 1999 Division of Forest Practices GIS statewide inventory of landslides (Boyd and Vaugeois, 2003). That database combines the 1:100,000-scale Division of Geology and Earth Resources digital maps of landslides with various other datasets of scales from 1:24,000 to 1:12,000.

The majority of datasets at a scale of 1:24,000 to 1:12,000 are from DNR studies by various departmental divisions. The rest of the datasets are from county or tribal records, or from other types of mapping projects. Polygons were originally entered as a single layer (with no overlapping polygons) and were separated to represent overlapping polygons. Every dataset has been converted, when possible, to the attribute-set within the Washington Geological Survey's Protocol.

For each selected dataset, the polygons and relevant attributes are incorporated into the Washington Geological Survey's landslide database. In the case of the Division of Forest Practices Landslide Database, landslides of the scale of 1:100,000 were separated from the scale of 1:24,000 and 1:12,000. This was done by overlaying the DGER 1:100,000 geologic map's landslide polygons and removing those polygons. The polygons were then hand-merged into single polygons and pasted into a new layer, allowing the polygons to be layered. Errors in attributes were noted in this process, to ensure data quality. The layered polygons were then entered into the Washington Geological Survey's landslide database and relevant attributes were inserted into the database.

The original landslide datasets will be preserved online for download, allowing the previous studies' unique attributes to be preserved and compared to those in the Washington Geological Survey's landslide database. Each dataset within this statewide database contains a unique code that allows the user to easily determine the source dataset for each landslide. This approach increases the usefulness of the database by linking it to the source information, thereby keeping the statewide database to a manageable size.

Emergency Response

An important aspect of landslide hazard reduction is real-time monitoring and emergency response (Spiker and Gori, 2000). In addition to hazard response, DGER intends to provide an online data collection form to encourage Washington citizens to report landslides of any size, in order to help maintain a comprehensive database. This form will request information regarding the size and type of landslide, material type, economic damage, etc. While not all citizens will be able to assess all aspects of landslides, this form will help to keep DGER geologists informed about potentially very large or very damaging events which would require field assessment. A landslide database form will require DGER geologists to participate in educational forums for Washington citizens, according to legislative mandate RCW 43.92.900 which states, "*It is the intent of the legislature that there be an effective State Geological Survey that can produce essential information that provides for the health, safety, and economic well-being of the citizens*."

Public Accessibility

ArcGIS is a specialized tool to which the general public generally does not have access. Therefore, in order to educate the general public, we have developed an ArcServer system that allows easy data acquisition and navigability of landslide features. Additionally, the landslide information will be accessible by KML/Z files, allowing the general public to access this layer of information on simplified spatial visualization programs (such as Google Earth). We also may provide RSS and GeoRSS feeds and corresponding Mapplets (Haefner and Venezky, 2007), for continuous updates during emergency events.

Not only will the public be able to use the information within the database for community planning or hazard mitigation, but an accessible database will bring the public's attention to the high landslide hazard in the Pacific Northwest. Hopefully, a more aware public is a better prepared public!

References

Bell, Brenda, 1999, The liquid earth: Atlantic Monthly, v. 283, no. 1, p. 58-72.

Boyd, Tom G., and Vaugeois, L.M., 2003, On the development of a statewide landslide inventory [abs.]: Geological Society of America Abstracts with Programs, v. 35, no. 6, p. 18.

Haefner, S.A., and Venezky, D.Y., 2007, Google mapplets for earthquakes and volcanic activity [abs.]: Eos, Transactions, v. 88, no. 52, Fall Meeting Supplemental, IN43A-0901, *http://www.agu.org/meetings/fm07/fm07-sessions/fm07_IN43A.html*.

Schuster, R.L., 1996, Socioeconomic significance of landslides, *in* Turner, A.K., and Schuster, R.L. (eds.), Landslides: Investigation and mitigation: Transportation Research Board, National Research Council, Special Report 247, p. 12-35.

Schuster, R.L., and Highland, L.M., 2001, Socioeconomic and environmental impacts of landslides in the Western Hemisphere: U.S. Geological Survey Open-File Report 01-0276, 47 p.

Spiker, E.C., and Gori, P.L., 2000, National Landslide Hazards Mitigation Strategy: A framework for loss reduction: U.S. Geological Survey Open-File Report 00-450, 49 p.

Washington State Department of Natural Resources, 2004, Landslide Hazard Zonation Project Protocol, version 2.0, accessed at *http://www.dnr.wa.gov/BusinessPermits/Topics/LandslideHazardZonation/Pages/fp_lhz_review.aspx*.

Improving the Legibility of Base Maps for Geologic Mapping at the Missouri Division of Geology and Land Survey

By Edith Starbuck and Karen Loveland

Missouri Department of Natural Resources
Division of Geology and Land Survey
P.O. Box 250
Rolla, MO 65402
Telephone: (573) 368-2136
Fax: (573) 368-2111
email: *edie.starbuck@dnr.mo.gov*

Summary

Legibility of base maps for compilation and publication of geologic maps is a significant concern at the Missouri Division of Geology and Land Survey (DGLS). Standard U.S. Geological Survey (USGS) digital raster graphics (DRGs) have been used, and their appearance can be improved by increasing the resampling ratio and dots per inch (dpi) when exporting the map from ArcMap. Scanning the paper topographic maps ourselves at 400 dpi and georeferencing them also creates an improved product. A third option under consideration is procuring a custom set of digital scans at 1200 dpi from the USGS. This paper will compare these options and discuss limitations imposed by the plotters available to us. Figure 1 demonstrates the improvement in base map quality by comparing the output from the selected method with that of previous years.

Reviewing the Options

For the past 12 years, geologists at the Missouri Division of Geology and Land Survey have been using standard USGS DRGs as base maps for geologic mapping projects. The geologic maps are currently produced using ArcGIS ArcMap, and the DRGs are used as a semi-transparent overlay. An HP 1055 plotter is currently used to plot the maps for publication. Printing hard copies of the map layout using a DRG as the base map often produces an unsatisfactory product. Topographic contour lines appear fuzzy and some lettering is illegible. Increasing the resampling ratio when printing helps improve the map's legibility, but the product still needs improvement. The maps are improved by printing at a resampling ratio of 1:2 (compared to 1:3, the default value), but the maps cannot be printed with a resampling ratio of 1:1 because the plotter memory is exceeded.

The Missouri DLGS is currently considering two options. One option is to purchase digital scans of the mylar map separates from the USGS. These scans are produced at 1200 dpi, and from approximately three to five digital scans per map would be required. Another option is to scan the paper topographic maps ourselves using our HP Designjet 4500 Scanner.

A third option is to replicate the USGS topographic map with hypsography, roads, and public land survey system datasets. This option is not currently being considered because the job of labeling the base map is so time consuming.

Producing Our Own Images

To produce the scanned images ourselves, the HP Designjet 4500 Scanner was used to scan paper USGS topographic maps at 400 dpi to produce a TIF image file. The file was then opened in Adobe Photoshop and converted to an indexed color image. The resulting TIF image file is then georeferenced in ArcMap.

In the past, the hard copy plots that are sent to the USGS, as part of the fulfillment of the STATEMAP contract, were

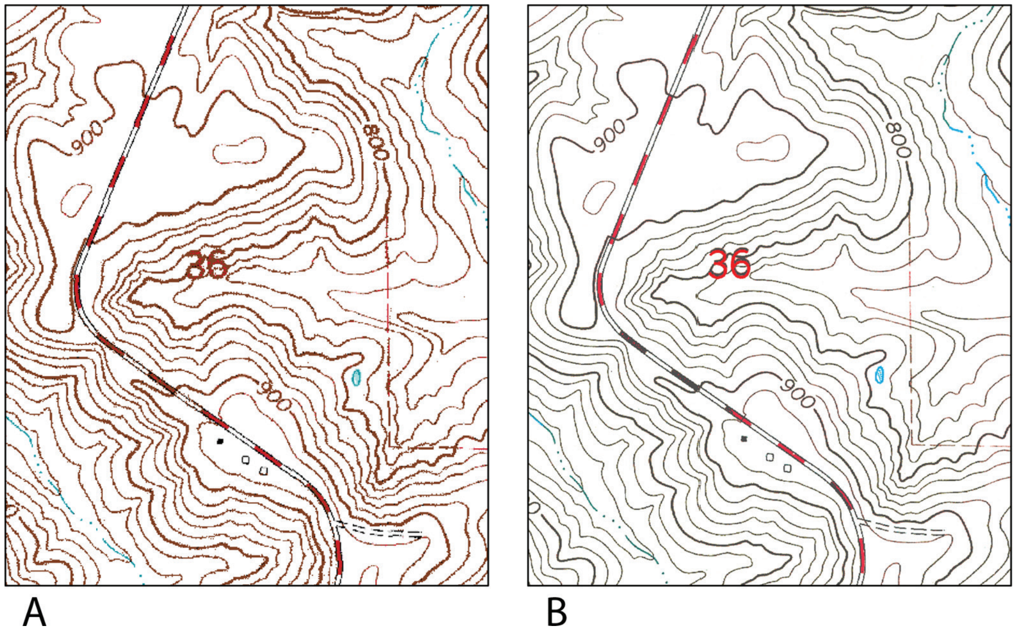


Figure 1. Base maps have been improved in two ways. The appearance has been muted by showing contour lines and text in dark gray. This allows the geology to be more prominently displayed. In addition, the DGLS has begun using DRGs that are produced in-house at higher resolution than the standard USGS DRGs. In this example, a paper topographic map was scanned at 400 dots per inch. The higher resolution base maps will improve the legibility of the final product and improve its appearance, particularly when users zoom in on the digital image. (A) USGS digital raster graphic plotted at 1:10,000 scale; the resolution of most USGS DRGs is 250 dots per inch. (B) Digital raster graphic created at DGLS and plotted at 1:10,000 scale; the DGLS scans paper topographic maps at a resolution of 400 dpi.

printed directly from ArcMap. However, for customers, the geologic maps are plotted on demand from the PDF files exported from ArcMap. A decision was made to put an emphasis on making certain that the plots provided to the public will be of a high quality. Fortunately, it was discovered that the plots from PDF files are equal in quality, or superior to the plots directly from ArcMap.

For the plots directly from ArcMap, the output image quality (resample ratio) varied. In general, the plots with a resample ratio of 1:3 were somewhat fuzzy, and contour lines appear discontinuous. Plots with a resample ratio of 1:1 could not be completed by the plotter. The best quality that could be achieved was with the resample ratio of 1:2.

For the plots from PDFs, the "Export Map" function was used to make the PDF, and the Resolution in dots per inch (dpi) and Output Image Quality (Resample Ratio) were varied. Other settings that were not varied are

- Destination Colorspace: RGB
- Compress Vector Graphics
- Image Compression: Deflate
- Picture Symbol: Rasterize layers with bitmap markers/fills
- Embed all document fonts

The files were opened and plotted from Adobe Reader. As might be expected, images with a resolution of 600 dpi and resample ratio of 1:2 look very similar to images with a resolution of 300 dpi and resample ratio of 1:1. The optimum settings were to export the map with a resolution of 400 dpi and a resample ratio of 1:1. Higher resolutions did not improve the appearance of the PDF plot because the topographic map was scanned at 400 dpi. The large files created at higher resolutions open and refresh slowly and did not print successfully.

USGS Digital Scans

The USGS Mapping Center in Rolla, MO, supplied us with samples of digital scans of map separates. These were copies of products that had been ordered by other customers and had been scanned at 1200 dpi. Attempts to plot the maps from ArcMap indicated that, again, the optimum resample ratio was 1:2. At a resample ratio of 1:3, the contour lines appear discontinuous and at 1:1, the plotter memory was exceeded.

A test geologic map was made by placing digital scans of three of the separates from the Nokesville, VA, quadrangle into an existing map layout. This map was exported from ArcMap to a PDF with a resample ratio of 1:1 and resolution of 400 dpi. The resulting plot was very legible. The lines are crisp and continuous, and the PDF file is smaller than the PDF file that was created when the geologic map was exported with the DGLS version of the topo map at the same resolution and resample ratio.

A Better Plotter

To determine the effect that a plotter with more memory would have on our product, we were permitted to use the Missouri Department of Natural Resources, Water Resources Center plotter, which is an HP Designjet 5500. The plots were printed faster, and large PDF files that could not be printed on the 1055 could be printed. However, the legibility of the base map was not significantly improved beyond that of the plots of the PDF files that were exported with a resample ratio of 1:1, a resolution of 400 dpi and plotted on the 1055. Changing the image used for the base map made a much more significant difference.

Resources

ArcGIS, GIS and Mapping Software, ESRI
http://www.esri.com/software/arcgis/index.html

HP Designjet 5500 Printer
http://h10010.www1.hp.com/wwpc/us/en/sm/WF06a/18972-18972-3328061-12600-3328080-82218.html

HP Designjet 4500 Scanner
http://h10010.www1.hp.com/wwpc/pscmisc/vac/us/product_pdfs/1143093.pdf

HP Designjet 1055 Printer
http://h41186.www4.hp.com/country/us/en/support/1055CM.html?pageseq=793510

Investigation of Geographic Rules for Improving Site-Conditions Mapping

By Chris Wills and Carlos Gutierrez

California Geological Survey
801 K St. MS 12-32
Sacramento, CA 95814-3531
Telephone: (916) 322-9317
Fax: (916) 322-4675
email: *cwills@consrv.ca.gov*

Introduction

This project attempts to contribute to improving characterization of the near-surface conditions of sites throughout California by developing geographic rules that may be used with geologic maps of California, and potentially extended to other areas. Explaining the variations in seismic shaking because of site conditions has been an ongoing research topic for over 20 years. Tinsley and Fumal (1985) assigned individual shear-wave velocities to each geologic unit in their test area, taking into account age, grain size and depth. In 1994, the Northridge earthquake resulted in unexpected variations in damage and ground motions in and around the Los Angeles area. Immediately, a number of studies were launched to study ground motions in southern California. Park and Elrick (1998) extracted the shear-wave velocity average to 30 meters (m) depth, Vs30. Their results show that Vs30 varies with grain size and age, and accordingly grouped the geologic units in southern California into eight different categories. Similarly, Wills and Silva (1998) assembled a database of shear-wave velocity measurements and correlated those with the materials described in borehole logs.

Wills and others (2000) published a site-conditions map for all of California based on the U.S. Geological Survey's National Earthquake Hazards Research Program (NEHRP) Vs30 categories, correlation of geologic units with Vs30 from Wills and Silva (1998) and generalization of the statewide 1:250,000 scale geologic maps. The "preliminary site conditions map" of Wills and others (2000) was found to correlate with seismic amplification (Field, 2000) and represented a credible first approximation for consideration of site conditions in seismic hazard estimates. Wills and others (2000) noted two main problems with this map: the lack of precision inherent in using the 1:250,000 scale geologic maps and the range of Vs30 in young alluvium due to variations in thickness, grain size and possibly regional differences in deposition and weathering.

More recent work by Wills and Clahan (2006) attempted to outline areas corresponding to geologic units with distinct Vs30. This effort provided an estimate of Vs30 for use in the Pacific Earthquake Engineering Research Center's Next Generation Attenuation (NGA) Equation project by applying the shear-wave velocity characteristics of geologic units, similar to the units described by Wills and Silva (1998), to all sites in the NGA database. This effort resulted in a set of 17 generalized geologic units that are classified by their shear-wave velocity, and a map of California showing those units. One key change in this map from previous maps is that we subdivided areas of young alluvium so that they are more homogenous in Vs30. Generally, our subcategories of young alluvium were defined geographically, rather than by using detailed geologic information. The geographic rules were kept as simple as possible: alluvium is expected to be thin in narrow valleys and small basins, coarse-grained near the base of steep mountains, and thick in the center of major basins. Using these rules, applied "by eye," the map prepared by Wills and Clahan (2006) separates geologic units within the young alluvium that appear to have different shear-wave velocity (Table 1). Deep basins with an abundance of shear-wave velocity information, the Imperial Valley and the Los Angeles basin, also can be shown to have significant regional differences in Vs30. Estimates of the mean and standard deviation of Vs30 from this map were provided to the NGA equation developers. All of the five attenuation equation developer

Table 1. Geologic units and shear-wave velocity characteristics developed by Wills and Clahan (2006). For each geologic unit, the number of profiles located in that map unit, the mean and standard deviation of Vs30 for those profiles, and the mean and standard deviation of the natural log (ln) of Vs30 are reported.

Geologic Unit	Geologic Description	Number of profiles	Mean Vs30	Std. Dev.	Vs30 from Mean of ln	Std. Dev. of ln
Qi	Intertidal Mud, including mud around the San Francisco Bay	20	160	39	155	0.243
af/qi	Artificial fill over intertidal mud around San Francisco Bay.	44	217	94	202	0.357
Qal, fine	Quaternary (Holocene) alluvium in areas where it is known to be fine.	13	236	55	229	0.238
Qal, deep	Quaternary (Holocene) alluvium in areas where it is more than 30m thick.	161	280	74	271	0.250
Qal, deep, Imperial V	Quaternary (Holocene) alluvium in the Imperial Valley	53	209	31	207	0.135
Qal, deep, LA Basin	Quaternary (Holocene) alluvium in the Los Angeles basin.	64	281	85	270	0.275
Qal, thin	Quaternary (Holocene) alluvium in narrow valleys, small basins, and adjacent to the edges of basins.	65	349	89	338	0.244
Qal, thin, west LA	Quaternary (Holocene) alluvium in part of west Los Angeles.	41	297	45	294	0.150
Qal, coarse	Quaternary (Holocene) alluvium near fronts of high, steep mountain ranges and in major channels.	18	354	82	345	0.223
Qoa	Quaternary (Pleistocene) alluvium	132	387	142	370	0.273
Qs	Quaternary (Pleistocene) sand deposits.	15	302	46	297	0.171
QT	Quaternary to Tertiary (Pleistocene - Pliocene) alluvial deposits.	18	455	150	438	0.266
Tsh	Tertiary (mostly Miocene and Pliocene) shale and siltstone units.	55	390	112	376	0.272
Tss	Tertiary (mostly Miocene, Oligocene, and Eocene) sandstone units.	24	515	215	477	0.386
Tv	Tertiary volcanic units.	3	609	155	597	0.240
Kss	Cretaceous sandstone of the Great Valley Sequence in the central Coast Ranges.	6	566	199	539	0.332
serpentine	Serpentine.	6	653	137	641	0.204
KJf	Franciscan complex rock.	32	782	359	712	0.432
xtaline	Crystalline rocks, including Cretaceous granitic rocks, and metamorphic rocks.	28	748	430	660	0.489

teams used estimates of Vs30, measured at the strong-motion instrument site or from this map, as their primary term for site conditions. The developer teams found that the Vs30 values from the new map were more effective in reducing the residuals in the ground motion than broader Vs categories based on NEHRP categories.

Like previous steps toward improved site-conditions mapping, preparation of the map by Wills and others (2006) has raised a series of questions:

- Is there a clear distinction based on the size of basin or width of valley that could do as well or better than the current visual classification of areas where thin alluvium affects Vs30?
- Can the higher velocities in "coarse alluvium" be related to geographic position at the base of high mountains or could they be due to soil formation in desert environments? Is it possible to separate these two effects?
- Can other geographic rules (e.g. distance from bedrock, slope, or surface roughness) do as well or better at differentiating Vs30 in alluvium?
- Are there systematic variations in Vs among "crystalline rocks"? Can those be correlated with slope, surface roughness, or other geographic criteria?
- How much can we improve estimation of Vs30 by using higher resolution geologic maps?

Developing Maps of Shear-Wave Velocity Based on Geologic Maps

Geologic maps use age, environment of deposition, and grain size to define units. Although the physical properties that control shear-wave velocity, such as grain size, density, and fracture spacing, do tend to vary between geologic units, they are not the defining criteria for most geologic units. As a result, there are numerous geologic units with essentially the same shear-wave velocity characteristics and there is considerable variability within most geologic units. For some classes of units, Tertiary shale for example, Vs30 values vary over a relatively small range, and the predicted variation in seismic amplification is small enough that the average Vs30 is a useful predictor of amplification on that type of materials. The challenge in preparing a map of shear-wave velocity based on geologic maps is to group those units that have similar velocity.

To prepare the statewide map of shear-wave velocity units, Wills and others (2000) and Wills and Clahan (2006) generalized from small-scale geologic maps that cover the State, grouping units with similar physical properties. One way to create more accurate and precise maps of shear-wave velocity is to use more detailed geologic maps. Larger-scale geologic maps ensure more precision in the location of contacts between geologic units and more accuracy in the description of geologic units, and in their assignment to shear-wave velocity classes. To test the potential improvements from using detailed geologic maps, we compiled geologic maps covering the Los Angeles basin and surrounding mountains and valleys. The geologic maps from Morton and Miller (2006), Saucedo and others (2003), and work in progress on the Los Angeles 1:100,000-scale quadrangle (California Geological Survey, in progress) were prepared from mapping conducted at 1:24,000 scale or larger and represent the most detailed available mapping for the area. The geologic units on those maps were classified according to the shear-wave velocity units of Wills and Clahan (2006). Two significant changes result from using these more detailed geologic maps, as illustrated in Figure 1. The first is that areas of young alluvium are more extensive on the more detailed maps. The second is that many of the Tertiary bedrock units that had been grouped with Tertiary shale in the generalized statewide map are shown on the more detailed maps as Tertiary sandstone.

Young alluvium is more commonly shown on detailed maps than on regional maps, particularly in the narrow valleys of mountainous areas. This occurs because narrow areas of alluvium in mountainous areas are simplified and removed from small-scale maps. In the Los Angeles area, the detailed maps show more young alluvium in mountain valleys and particularly in the hills east of downtown Los Angeles. Within the Los Angeles region as shown on Figure 2, the area of young alluvium on the more detailed maps is 4 percent larger than the area shown on the generalized maps. This increase represents 110 square kilometers, most of which had been mapped as bedrock. Most of the additional areas are thin alluvium in narrow valleys or at the base of mountains and therefore they have velocities higher than alluvium in the deep basins, but lower than most bedrock.

Tertiary sedimentary rocks were divided into sandstone and shale for the preliminary shear-wave velocity map of California (Wills and others, 2000), which was based on units shown on the 1:250,000 scale Geologic Atlas of California (published between 1958 and 1972) and a few more recent maps. The units on the Geologic Atlas are defined by time, rather than lithology, however. Wills and others (2000) grouped all Paleocene, Eocene, and Oligocene rocks as sandstone, and Miocene and Pliocene rocks as shale, because as a statewide generalization, more of the early Tertiary rocks are sandstone whereas more of the late Tertiary rocks are shale. In detail, however, there are many areas where this generalization is not correct. In the Los Angeles area, this generalization resulted in sandstones of the Topanga, Puente and Fernando Formations, among others, being grouped with

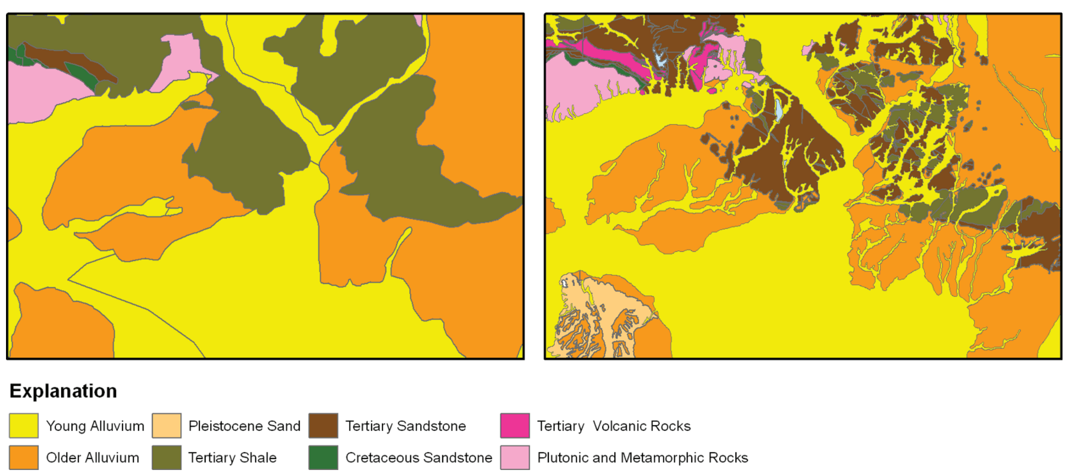


Figure 1. Examples of the difference in using more detailed geologic maps in preparation of shear-wave velocity maps. These two maps show the Los Angeles and Hollywood 7.5-minute quadrangles, some of the most densely populated parts of the Los Angeles region. The area shown is about 15 miles across. The left map is from the statewide map prepared by Wills and Clahan (2006), based on small-scale geologic maps. The right map is based on 1:24,000 mapping prepared for the CGS Seismic Hazard Mapping Program by Mattison and Loyd (1998a, b). [A more legible color version of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_GutierrezFig1.pdf*]

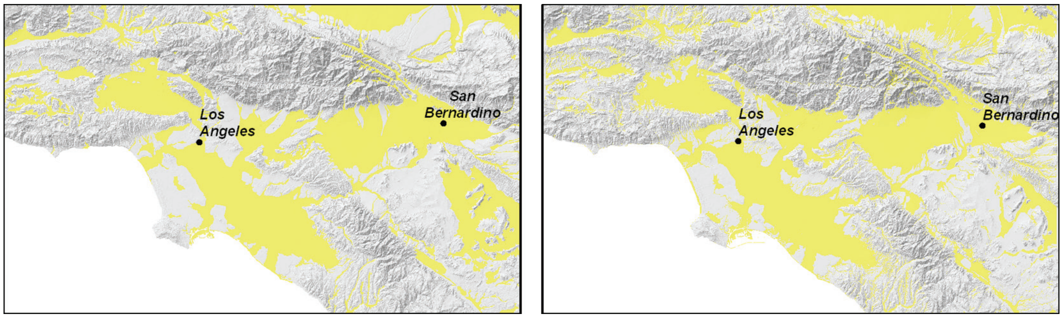


Figure 2. Examples of the difference in extent of young alluvium, shown in yellow, depicted on generalized and more detailed geologic maps. These two maps show the Los Angeles and surrounding areas that were included in this study. The left map is derived from the statewide map prepared by Wills and Clahan (2006), based on small-scale geologic maps. The right map is based on more detailed 1:24,000 mapping. Within the Los Angeles region, the area of young alluvium on the more detailed maps is 4 percent larger than the area shown on the generalized maps. [A more legible color version of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_GutierrezFig2.pdf*]

shale. With the more detailed maps, and designations based on lithologic descriptions of the individual units, the area mapped as shale is only 40 percent of the previous map, while the area mapped as sandstone increased by a factor of more than three.

Based on the above comparison in the Los Angeles area, detailed geologic maps result in more accurate maps of shear-wave velocity both because of the inherent increase in the precision of the mapping and also because of the ability to test and revise simplifying assumptions that are required when working with more generalized maps.

Developing Maps of Shear-Wave Velocity in Alluvial Basins

Differentiating shear-wave velocity units is most important for recently deposited materials, because these materials tend to have the lowest velocities and therefore the greatest potential for seismic amplification. Recent deposits in basins and plains are also where people tend to settle and urban centers grow. Variations in amplification across an urban area, because of variations in shear wave velocity between different geologic materials, can have a significant effect on the area's distribution of earthquake damage and losses.

In some cases, there is a simple correspondence between geologic unit characteristics and velocity. For example, estuarine or marsh deposits tend to be rapidly deposited silt and clay, of low density. Because estuarine deposits are recognized as having different properties from the surrounding deposits, they are usually mapped as geologic units. They also have a narrow range of shear-wave velocity so these "bay mud" and "intertidal mud" deposits have long been recognized as areas of enhanced seismic shaking. Other geologic units, alluvial fan deposits in particular, can have a wide range of density and grain size. Recent alluvial deposits range in Vs30 from about 200 to about 400 meters per second (m/s), which overlaps the range of "bay mud" at the low end and the range of "soft rock" at the high end. This range in Vs30 results in a range of amplification that is also about a factor of two (graphs in Wald and Mori, 2000). This range in velocity is related to the density and grain size of the deposit, as well as soil forming processes that, with time, can increase velocity by filling pore spaces with clay or calcium carbonate or decrease velocity by the weathering of large clasts.

Although the factors that lead to the large range of shear-wave velocity in recently deposited alluvium are well recognized, a poor correlation between geologic (or "soils") map units has repeatedly been noted. Thelen and others (2006) showed that 50 measurements of Vs30 in coarse alluvium of the northern San Gabriel Valley had an average velocity above the range predicted for the NEHRP-based CD Site Class (mean Vs30 of 360 m/s), and large variance. In Las Vegas and Reno, NV, Scott and others (2004, 2006) found poor Vs30 predictability from mapped alluvial units. Park and Elrick (1998), and Steidl (2000) attempted to correlate geologic maps of southern California with seismic amplification, without much success. Steidl did not even find significant differences in amplification between younger and older alluvium, probably because of the way those units were defined and mapped on the maps that he used in his study.

There may be many reasons for poor correlation between mapped geologic units and Vs30 in Quaternary deposits, but some basic reasons can be inferred from the nature of geologic maps of Quaternary deposits and the methods by which they are made. Geologic maps use divisions of geologic time as the first level discriminator between units. This is useful because "older alluvium" or "Pleistocene alluvium" commonly includes all alluvial deposits where soil-forming processes, compaction, and cementation have significantly raised the shear-wave velocity. Older alluvium also has a narrow enough range of Vs30 that it is mapped as a single site-condition category on the map of Wills and Clahan (2006). Geologic maps commonly use environment of deposition as a second level discriminator between geologic units. This can be useful when environment of deposition leads to a narrow range of grain size and density, as in estuarine deposits discussed above. Recent alluvial fan and basin deposits are commonly mapped as "Younger alluvium" or "Holocene alluvium." These deposits underlie areas of active or recently active deposition of sediment, with slight or no modification due to cementation or weathering. Because these deposits underlie large areas within urban regions, several methods have been developed to further subdivide these units. Third-level discriminators of geologic units within young alluvial fans are most commonly based on age, commonly with additional descriptors based on grain size. These subdivisions within recent alluvial fan deposits depend on interpretations of the relative age of geomorphic surfaces and on descriptions of the near-surface materials from boreholes or test pits.

The subdivisions within Holocene (recent) alluvial fan deposits have proven most problematic for correlating between geologic maps and shear-wave velocity. It seems clear that geologic maps show detailed units defined by typical grain size within areas of young alluvium. Since grain size is the principal physical difference between alluvial deposits that have different shear-wave velocity, these units should correlate with Vs30. The most common result of studies to examine this correlation is that areas mapped as coarse alluvium have no significant difference from those mapped as fine alluvium (Park and Elrick, 1998; Steidl, 2000; Scott and others, 2004, 2006). This disappointing result has led some to doubt the value of geologic maps for estimating Vs30. This result is not surprising, however, when one considers how these maps are made and the patterns of deposition of materials on alluvial fans. Geologic maps that show variations in grain size in recent alluvium are almost always based on information from the upper few meters of the deposits. On alluvial fans, the locations of channels, where coarser materials are deposited moves across the fan over time. In cross section, deposits tend to be a mass of the average grain size of the fan with lenses of coarser grained materials representing the channel deposits. Any point on the fan may be underlain by material representing sheet flooding over the body of the fan as well as channel deposits. The proportions of those materials do not change depending on whether a coarser channel deposit happens to be at the surface. As a result, grain size designations based on the materials at the surface are commonly not representative of the average of the materials within the upper 30 m.

An additional problem in correlating Vs30 with the material at the surface, and represented on geologic maps, is that Holocene alluvium is rarely 30 m thick. Where the young alluvium is thinner, Vs30 can be strongly influenced by the underlying material. This can be a significant issue where alluvium at the surface is underlain by material with much higher velocity, such as crystalline bedrock. Fortunately, locations where "thin alluvium" is found can be anticipated. Wills and Clahan (2006) designated areas at the edges of large basins and in narrow valleys as "thin alluvium" based only on distance from the basin edge. Boundaries drawn by Wills and Clahan (2006) a few kilometers from the edges of most alluvial basins in California did separate measured profiles in "deep alluvium" with a mean Vs30 of about 280 m/s from those in "thin alluvium" with a mean Vs30 of about 350 m/s.

Young alluvium is typically deposited in a subsiding basin. Since such basins have formed over much longer time scales than the Holocene, younger alluvium at the surface is typically underlain by older alluvium with somewhat similar properties. In this typical case, where young alluvium overlies older alluvium, the thickness of the young alluvium appears to be less significant than the thickness of the older alluvium. In the west Los Angeles area, 41 shear-wave velocity profiles have been measured in an area where geologic logs clearly document less than 30 m of young alluvium underlain by older alluvium. The mean Vs30 for this area is not significantly different from the mean Vs30 for deep alluvium in the Los Angeles basin, or from deep alluvium in other basins in California (Wills and Clahan, 2006).

Any system to predict the Vs30 in young alluvial deposits needs to consider several concepts outlined above:

1. Differences in Vs in young alluvial deposits correlate with grain size. Compaction, soil formation and cementation have lesser effects.

2. Grain size of the surface material does not reliably indicate the average grain size in the upper 30 m.

3. Grain size generally decreases downstream from the apex of an alluvial fan.

4. Slope of alluvial fans also decreases downstream from the apex, so there should be a positive correlation between slope and average grain size.

5. The thickness of the young alluvial deposits has a significant effect on Vs30 where harder material is within 30 m of the surface. The effect does not appear to be significant where the young alluvium is underlain by older alluvium.

Wills and Clahan (2006) made use of these concepts in developing their geologically based Vs30 map of California. In this study we hope to refine the rules they used in making their map, examine the relative importance of different factors, and apply the rules that best distinguish Vs30 categories to detailed geologic maps.

Since grain size at the surface of an alluvial fan deposit has only slight predictive power for the average grain size in the upper 30 m, and does not distinguish areas where the alluvium is less than 30 m thick, an alternate method is needed to distinguish Vs30 units in young alluvium. Two methods have been attempted: either construct a detailed three-dimensional model showing the variation in thickness of deposits and their different velocities, or identify some useful proxy for the average grain size within an alluvial fan deposit. Tinsley and Fumal (1985) and Holzer and others (2005) have demonstrated that three-dimensional models showing the thickness of layers with differing velocity can be used to predict Vs30, or other parameters, across parts of the Los Angeles and San Francisco-Oakland urban areas. Constructing a three-dimensional velocity model of the upper 30 m is very time- and data-intensive, however, so if site-conditions maps of large areas are needed, a useful proxy for average grain size must be found.

For this study we tested two potentially useful proxies for Vs30 in young alluvium. Both take advantage of the decrease in the average grain size in alluvial fan deposits with distance from the apex of the fan. Since the apex of the fan, the point where the stream begins to deposit material, commonly coincides with a mountain front, grain size typically decreases with distance from the mountain front. Similarly, the stream's gradient, and its ability to transport material, decreases away from the mountain front. The result is relatively steep, coarse-grained deposits near the mountain front grading into less steep, finer grained alluvial deposits farther away. The distal alluvial fan deposits may grade into basin, marsh, lake, or fluvial deposits that have even lower gradients. A system for dividing young alluvial deposits by average grain size could take advantage of the decrease in grain size with distance from the source, or the decrease with stream gradient (slope of the surface of the fan).

For the map of Wills and Clahan (2006), young alluvium is divided into eight different categories: Qal, fine; Qal, deep; Qal, deep, Imperial V; Qal, deep, LA basin; Qal, thin; Qal, thin, west LA; and Qal, coarse. These categories take advantage of the general velocity gradient away from mountain fronts, and the available subsurface data that show where the alluvium in the subsurface is generally fine, or show that alluvium in one basin (the Imperial Valley) has lower velocity than in other basins in the State. In order to test more general rules for subdividing the younger alluvium, we have combined all these mapped categories into one and then split that map unit based on geographic rules that may be useful proxies for grain size and Vs30. The overall goal is to find methods that result in well-defined, reproducible polygons that have smaller ranges of Vs30 than the interpretive polygons of Wills and Clahan (2006). For this analysis we are using the same database of Vs30 measurements as used in that earlier work.

Variability of Vs30 in Young Alluvium, with Lateral Distance from Rock

In reviewing the measured shear-wave velocity in young alluvium, Wills and Silva (1998) noted that near the edges of alluvial basins Vs30 tended to be higher and much more variable, largely because certain 30-m profiles included young alluvium over higher velocity material. This led Wills and Clahan (2006) to establish a unit they called "thin alluvium" designated simply by assuming that the alluvium in narrow valleys, small basins and close to the edges of larger basins may be less than 30 m thick. The geographic limits of this were drawn "by eye." The Vs30 in "thin alluvium" designated in this way does appear to be higher and more variable in Vs30 than in "deep alluvium" (Table 1). Unfortunately, because the geographic extent of these areas was approximately drawn based on individual judgment, application to other areas is difficult. In order to apply the same rules in a more systematic way, we have tested the variability of Vs30 in young alluvium with distance from "rock."

To test variability of Vs30 in young alluvium with distance from rock, we used the digital map of Wills and Clahan (2006) and drew polygons enclosing areas within 1, 2, 5, and 10 km from rock. We included Tertiary sandstone and shale, Franciscan and other Cretaceous rocks, and all metamorphic, volcanic, and plutonic rocks in the "rock" category. Older alluvium and Pliocene-Pleistocene alluvial units were not included as "rock". A distance category corresponding to one of these "distance from rock" polygons was then applied to each site where shear-wave velocity has been measured. Sorting the Vs30 measurements by distance category yields the values shown in Table 2 and Figure 3.

Table 2. Vs30 values in young alluvium sorted by distance from rock.

	0-1 km	1-2 km	2-5 km	5-10 km	>10 km
Mean	328.7	314.0	298.0	262.0	212.8
Standard Deviation	96.5	67.3	63.2	59.8	31.6
Mean+SD	425.2	381.3	361.2	321.9	244.5
Mean-SD	232.3	246.7	234.7	202.2	181.2
Minimum	190.0	212.0	172.4	150.6	162.9
Maximum	629.0	452.9	457	478.1	318.4
Count	107	51	59	68	64

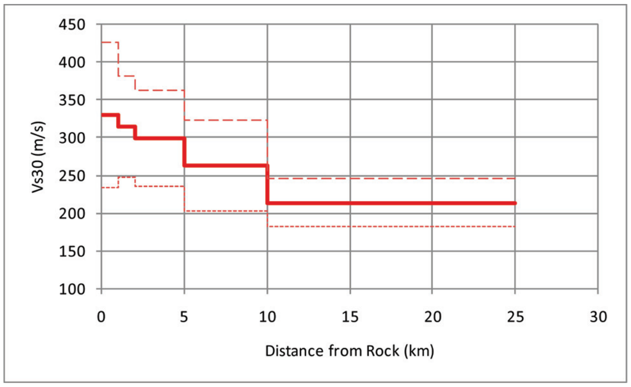


Figure 3. Variation of Vs30 with distance from rock. The solid red line represents the mean Vs30, the dashed red line represents the mean Vs30 plus the standard deviation, and the dotted red line represents the mean Vs30 minus the standard deviation.

As expected, mean Vs decreases with distance from rock. The variability in Vs30 also appears to decrease significantly with distance. The decrease in variability is most apparent between sites from 0-1 km and those from 1-2 km, suggesting that sites more than 1 km from the edge of an alluvial basin are much less likely to encounter higher velocity material within 30 m of the surface. Variability of Vs30 in young alluvium also appears to decrease at distances of over 10 km from rock. This may be because the alluvial deposits at distances greater than 10 km from rock tend to be basin and floodplain deposits composed of silty sand and clay.

Variability of Vs30 in Young Alluvium, with Slope

Another option for subdividing young alluvial deposits is to sort them by the slope of the ground surface. Slope reflects the stream gradient, and therefore the stream's ability to transport material. Thelen and others (2006) noted that for a series of Vs profiles along the San Gabriel River across the Los Angeles basin, Vs30 was proportional to stream power. On a much larger scale, Wald and Allen (2007) proposed that surface slope in all materials could be a useful proxy for Vs30. Although Wald and Allen showed a correlation between slope and Vs30, and this appears to be a useful first approximation, the correlation probably reflects a number of separate causes. In depositional areas, the correlation between slope and Vs30 probably reflects stream power, as proposed by Thelen and others In erosional areas, in contrast, slope may reflect the surface material's resistance to erosion. Although both of these factors may lead to a correlation between higher velocity and steeper slopes, we have examined the correlation of Vs30 with slope in young alluvium (in depositional settings), not the correlation of Vs30 with slope in bedrock (in erosional settings).

Creation of Slope Maps from Digital Elevation Models

Digital Elevation Model Selection

Digital Elevation Models (DEMs) are digital representations of the Earth's surface and are available from various sources, at various resolutions and extents. For this study we chose to compare elevation data from the USGS National Elevation Dataset (NED) (available at *http://ned.usgs.gov/*) and NASA's Shuttle Radar Topography Mission (SRTM) (available at *http://www2.jpl.nasa.gov/srtm/*). These datasets are available in resolutions ranging from 10 to 90 m (1/3 arc-second to 3 arc-second) and both cover the entire State of California.

In order to determine which dataset was better suited for the purpose of producing a statewide slope map, we generated preliminary shaded relief and slope maps using Environmental Systems Research Institute's (ESRI) ArcInfo – ArcGIS, version 9.2, and the ArcGIS Spatial Analyst extension. A cursory review of the maps revealed that the 90-m datasets produced a better generalized surface than the higher resolution data which contained many unwanted artifacts. Further comparisons between the 90-m USGS and 3 arc-second SRTM data revealed that the SRTM data still contained many artifacts, possibly related to vegetation and/or manmade structures, producing an overall rougher surface (Figure 4). Therefore, the 90-m USGS dataset was chosen for our slope analysis. The selected USGS dataset was derived from the USGS 1 arc-second (30-m cell size), 1:24,000-scale seamless DEM. The statewide DEM was projected from decimal degrees to Albers conic, and resampled to a 90-m cell size.

DEM Preparation

In many areas, the digital elevation data produced by the USGS are derived from the interpolation of contour lines. As a result, "step-like" or "rice paddy" artifacts are visible on derivative shaded relief and slope maps. To reduce the effect of these artifacts and obtain a better estimate of slope, the 90-m DEM grid was generalized by calculating the mean elevation value over a specified neighborhood of pixels and applying the calculated value to the central pixel. We generated three generalized slope grids using a 3x3, 5x5, and 9x9 pixel square and compared the results (Figure 5). All generalization processes were effective in diminishing artifacts from the original dataset, but the 9x9 pixel square generalization produced the best definition of large-scale geomorphic features such as alluvial fans and depositional basins.

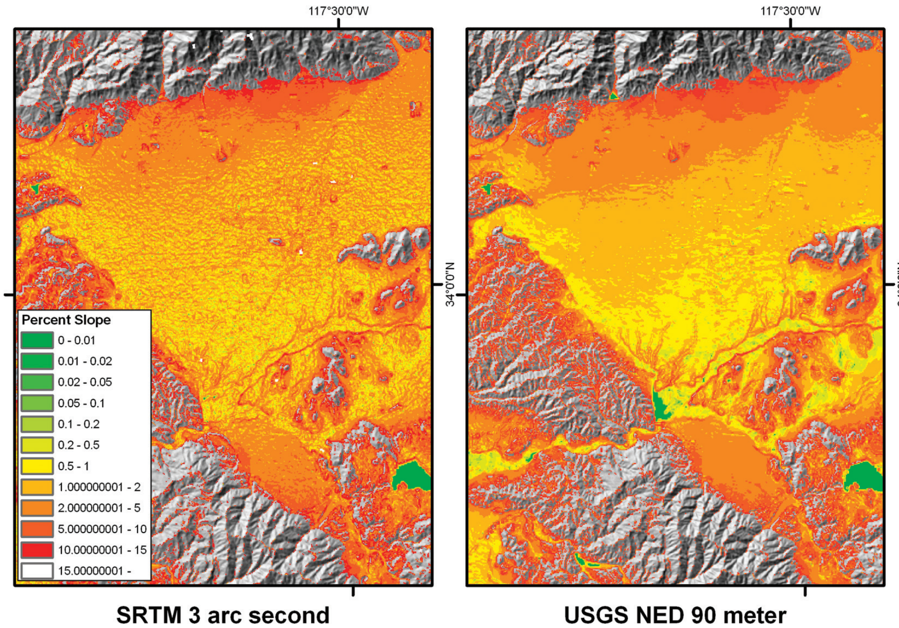


Figure 4. Example of preliminary slope maps generated from the SRTM 3 arc-second and USGS NED 90-m datasets. Note the rough surface depicted in the slope map derived from the SRTM data compared to the slope map derived from the USGS NED data. [A more legible color version of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_GutierrezFig4.pdf*]

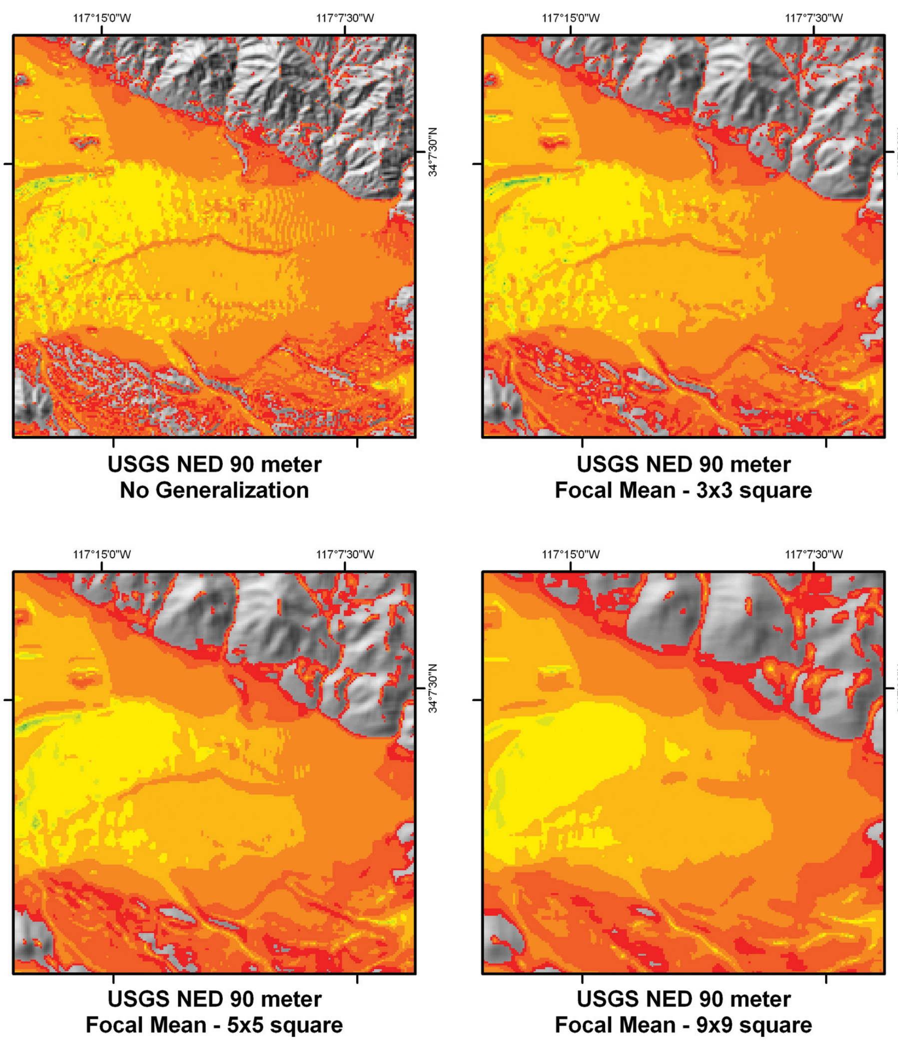


Figure 5. Example of artifacts visible in preliminary slope maps derived from the original unmodified dataset and datasets resulting from the generalization process over a 3x3, 5x5, and 9x9 pixel square. [A more legible color version of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_GutierrezFig5.pdf*]

Slope Map Generation

As described above, the USGS NED 90-m DEM was prepared using a generalization process in order to remove artifacts inherent to the data. Spatial Analyst was then used to process the generalized DEM and create a grid depicting the percent slope for each pixel. The slope grid was originally reclassified into 12 classes as shown in Table 3 and graphically shown in Figure 6. Upon examining the data, we found there were only a few or no profiles in each of the four flattest slope categories, and so all measurements less than 0.1 percent slope were grouped into one category. The reclassified slope grid was then used to create a polygon shapefile from contiguous pixels of the same slope class using the "Convert Raster to Features" function in Spatial Analyst.

Table 3. Slope categories originally correlated with Vs30.

Percent Slope	Number of profiles	Mean Vs30	Sd of Vs30
0 - 0.01	*		
0.01 - 0.02	*		
0.02 - 0.05	*		
0.05 - 0.1	21	224	34
0.1 - 0.2	43	227	47
0.2 - 0.5	61	248	54
0.5 - 1	75	303	74
1 - 2	49	320	91
2 - 5	58	356	86
5 - 10	14	353	87
10 - 15			
15 -			
* insufficient data, grouped with category below			

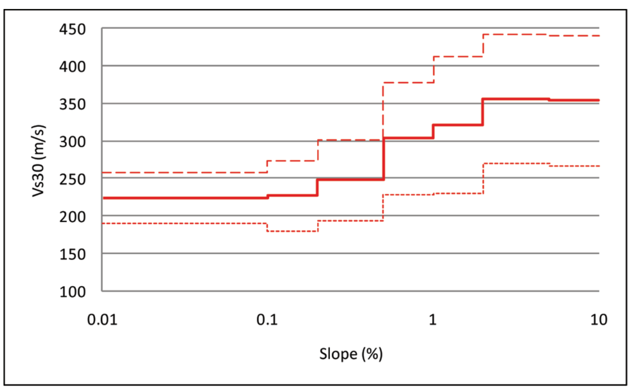


Figure 6. Variation of Vs30 with slope, all categories shown. The solid red line represents the mean Vs30, the dashed red line represents the mean Vs30 plus the standard deviation, and the dotted red line represents the mean Vs30 minus the standard deviation.

Based on our initial analysis, it appeared that the number of slope categories could be further reduced, and the resulting maps simplified. In depicting the boundaries of slope categories on geologic maps, we found that in several cases there appeared to be a coincidence between the 0.5 percent slope boundary from the slope map with the boundary between the lower ends of alluvial fans and adjoining basin or floodplain deposits. Vs30 between 0.5 percent and 1.0 percent appeared similar to Vs30 between 1.0 percent and 2.0 percent, and Vs30 between 2.0 percent and 5.0 percent appeared similar to Vs30 between 5.0 percent and 10.0 percent. We therefore tested whether three simplified categories could subdivide the Vs30 in young alluvium. The results of that test are shown in Table 4 and Figure 7. Comparing the mean and standard deviation of Vs30 with the categories defined by Wills and Clahan (2006) (Table 1) shows that these simplified slope categories result in fewer ranges of Vs30 in young alluvium, and ranges that have comparable standard deviations. This result for the California data, and the potential that the same slope categories can be used in other areas, suggests that these simplified slope categories can be used to develop the next generation map of shallow shear-wave velocity.

Table 4. Simplified slope categories used to develop shallow shear wave velocity.

Slope	Number of profiles	Mean Vs30	Sd of Vs30
≤0.5	169	231	55
0.5-2	124	306	78
>2	73	353	87

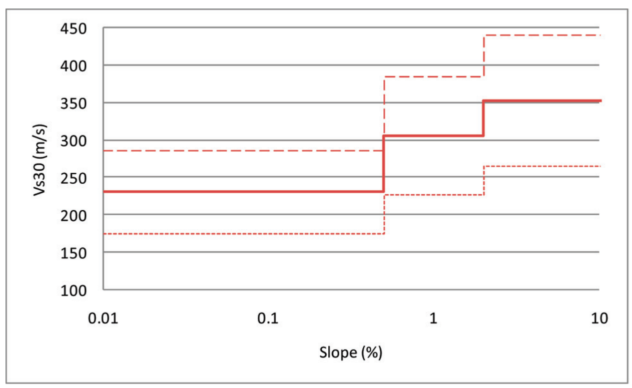
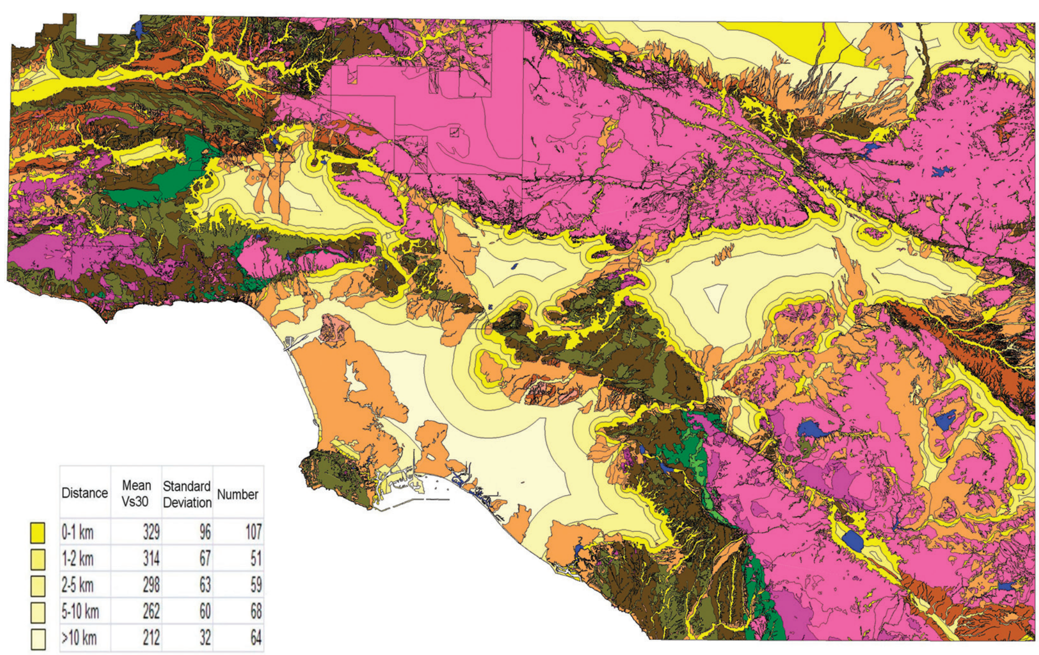


Figure 7. Variation of Vs30 for three simplified slope categories. The solid red line represents the mean Vs30, the dashed red line represents the mean Vs30 plus the standard deviation, and the dotted red line represents the mean Vs30 minus the standard deviation.

Discussion

We have developed two rules that can be applied with available GIS data to develop maps of shear-wave velocity. Subdividing areas underlain by young alluvium either by distance from bedrock or by slope results in polygons with ranges of Vs30 values that are at least as well-defined as the ranges for polygons from the map of Wills and Clahan (2006) using a method that is more objective and reproducible. Either of these rules will allow completion of revised shear-wave velocity maps of California, or potentially of other areas, that define areas with specific ranges of Vs30 as well or better than the previous map and method.

The remaining questions are which of these two rules produces the better delineation of shear-wave velocity classes, and which produces the best correlation with seismic amplification? A study of the correlation of either of these maps with seismic amplification is beyond the scope of this study, but correlations with other geological features suggest that subdivision based on slope is likely to provide better correlation with amplification. One distinct difference between the slope-based and the distance-based maps of the Los Angeles area (Figures 8 and 9) is that the distance-based rule results in concentric gradation of predicted Vs30 in the larger alluvial basins, whereas the slope-based rule results in asymmetric gradation of predicted Vs30. The asymmetric slopes of the San Fernando, San Gabriel, and upper Santa Ana River basins are the result of large alluvial fans that have their sources in the San Gabriel and San Bernardino Mountains north of the Los Angeles Basin, and much smaller uplifts and resultant alluvial fans along the south sides of those basins. The topography and mapped geology delineate steep, coarse-grained alluvial fans along the northern edges of these basins which grade to less-steep and finer grained deposits to the south. In each of these basins, the finest-grained materials, and many of the low Vs30 measurements, are along the southern edges of these basins, where a distance from bedrock rule would predict relatively high Vs30. Although the statewide dataset does not clearly distinguish the slope-based rule for subdividing young alluvium as better than the distance-based rule, slope appears to more clearly correlate with grain size and possibly with Vs30 in these asymmetric basins. Additionally, as noted above, the boundary on the slope maps between slopes steeper and less steep than 0.5 percent coincides with a boundary on some geologic maps between sandy and gravelly alluvial fan deposits and floodplain and basin deposits that are commonly finer grained. This coincidence suggests that a slope-based boundary may have better correlation with grain size than the distance-based boundaries.



Distance	Mean Vs30	Standard Deviation	Number
0-1 km	329	96	107
1-2 km	314	67	51
2-5 km	298	63	59
5-10 km	262	60	68
>10 km	212	32	64

Figure 8. Preliminary map of shear-wave velocity in the Los Angeles region using detailed (1:24,000) geologic maps, the lateral distance from bedrock as a method to classify younger alluvium, and the classification of Wills and Clahan (2006) for other units. Young alluvium shown in shades of yellow, other units as defined on Figure 1. Using distance from bedrock and larger scale geologic maps results in better definition of velocity categories and more precision in location of boundaries than that of the previous statewide map. [A more legible color version of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_GutierrezFig8.pdf*]

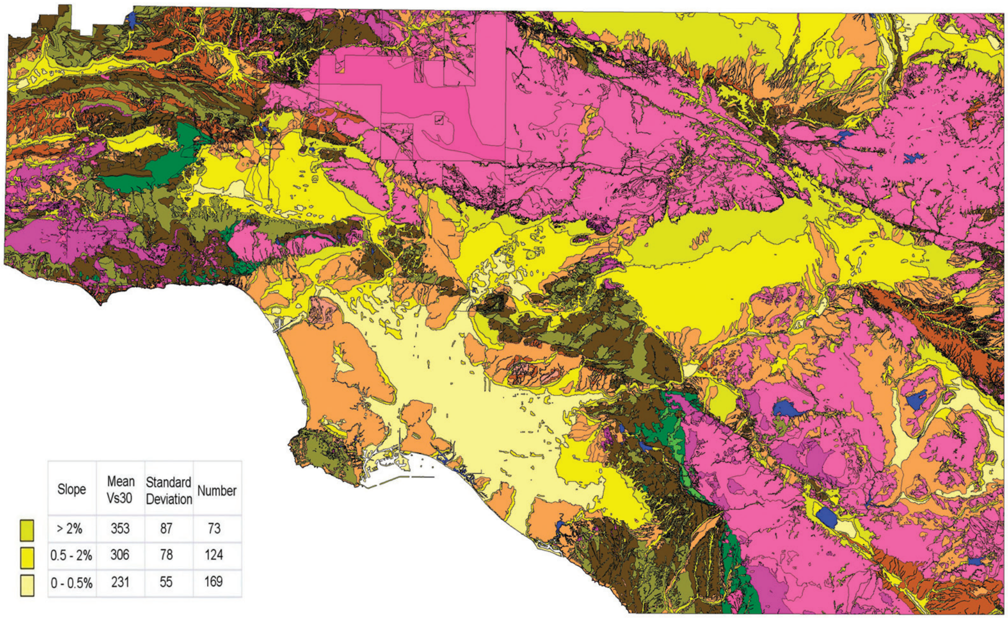


Figure 9. Preliminary map of shear-wave velocity in the Los Angeles region using detailed (1:24,000) geologic maps, land slope as a method to classify younger alluvium, and the classification of Wills and Clahan (2006) for other units. Young alluvium shown in shades of yellow, other units as defined on Figure 1. Using slope and larger scale geologic maps results in better definition of velocity categories and more precision in location of boundaries than that of the previous statewide map. [A more legible color version of this figure is available at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT08_GutierrezFig9.pdf*]

Acknowledgments

The authors thank David Wald and Alan Yong of the USGS, Aasha Pancha and John Louie of the University of Nevada, Reno, and Walt Silva of Pacific Engineering and Analysis for their discussions of velocity data and mapping methods. This research was supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 07HQGR0061. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

References

Field, E.H., 2000, A modified ground motion attenuation relationship for southern California that accounts for detailed site classification and a basin depth effect: Bulletin of the Seismological Society of America, v. 90, no. 68B, p. S209-S221.

Holzer, T.L., Bennett, M.J., Noce, T.E., and Tinsley, J.C., III, 2005, Shear-wave velocity of surficial geologic sediments in Northern California: Statistical distributions and depth dependence: Earthquake Spectra, v. 21, no. 1, p. 161-177.

Mattison, E., and Loyd, R.C., 1998a, Liquefaction zones in the Hollywood 7.5-minute Quadrangle, Los Angeles County, California: California Geological Survey Seismic Hazard Report 026, 47 p., accessed at *http://gmw.consrv.ca.gov/shmp/download/evalrpt/holly_eval.pdf*.

Mattison, E., and Loyd, R.C., 1998b, Liquefaction zones in the Los Angeles 7.5-minute Quadrangle, Los Angeles County, California: California Geological Survey Seismic Hazard Report 029, 41 p., accessed at *http://gmw.consrv.ca.gov/shmp/download/evalrpt/la_eval.pdf*.

Morton, D.M., and Miller, F.K., 2006, Geologic map of the San Bernardino and Santa Ana 30' x 60' quadrangles, California: U.S. Geological Survey Open-File Report 2006-1217.

Park, S., and Elrick, S., 1998, Predictions of shear-wave velocities in southern California using surface geology: Bulletin of the Seismological Society of America, v. 88, no. 3, p. 677-685.

Saucedo, G.J., Greene, H.G., Kennedy, M.P., and Bezore, S.P., 2003, Geologic map of the Long Beach 30' X 60' Quadrangle: California Geological Survey Regional Geologic Map Series, 1:100,000 scale, Map No. 5, Version 1.0, accessed at *ftp://ftp.consrv.ca.gov/pub/dmg/rgmp/Prelim_geo_pdf/lb_geol-dem.pdf*.

Scott, J.B., Clark, M., Rennie, T., Pancha, A., Park, H., and Louie, J.N., 2004, A shallow shear-wave velocity transect across the Reno, Nevada area basin: Bulletin of the Seismological Society of America, v. 94, no. 6, p. 2222-2228.

Scott, J.B., Rasmussen, T., Luke, B., Taylor, W., Wagoner, J.L., Smith, S.B., and Louie, J.N., 2006, Shallow shear velocity and seismic microzonation of the urban Las Vegas, Nevada basin: Bulletin of the Seismological Society of America, v. 96, no. 3, p. 1068-1077, accessed at *http://www.seismo.unr.edu/hazsurv/2005044_Scott-pp.pdf*.

Steidl, J.H., 2000, Site response in Southern California for probabilistic seismic hazard analysis: Bulletin of the Seismological Society of America: v. 90, no. 6B, p. S149-S169.

Thelen, W.A., Clark, M., Lopez, C.T., Loughner, C., Park, H., Scott, J.B., Smith, S.B., Greschke, B., and Louie, J.N., 2006, A transect of 200 shallow shear velocity profiles across the Los Angeles Basin: Bulletin of the Seismological Society of America, v. 96, no. 3, p. 1055-1067.

Tinsley, J.C., and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response, *in* Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region – An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 101-126.

Wald, D.J., and Allen, T.I., 2007, Topographic slope as a proxy for seismic site conditions and amplification: Bulletin of the Seismological Society of America, v. 97, no. 5, p. 1379-1395.

Wald, L.A., and Mori, J., 2000, Evaluation of methods for estimating linear site-response amplifications in the Los Angeles region**:** Bulletin of the Seismological Society of America, v. 90, no. 6B, p. S32-S42.

Wills, C.J., and Clahan, K.B., 2004, NGA: Site condition metadata from geology: Report prepared for the Pacific Earthquake Engineering Research Center, Project 1L05.

Wills, C.J., and Clahan, K.B., 2006, Developing a map of geologically defined site-conditions categories for California: Bulletin of the Seismological Society of America, v. 96, no. 4A, p. 1483-1501.

Wills, C.J., Petersen, M., Bryant, W., Reichle, M., Saucedo, G., Tan, S., Taylor, G., and Treiman, J., 2000, A site-condition map for California based on geology and shear-wave velocity: Bulletin of the Seismological Society of America, v. 90, no. 6B, p. S187-S208.

Wills, C.J., and Silva, W., 1998, Shear wave velocity characteristics of geologic units in California: Earthquake Spectra, v. 14, no. 3, p. 533-556.

USGS

Soller, ed.—**Digital Mapping Techniques '08—Workshop Proceedings**—Open-File Report 2009–1298

Printed on recycled paper