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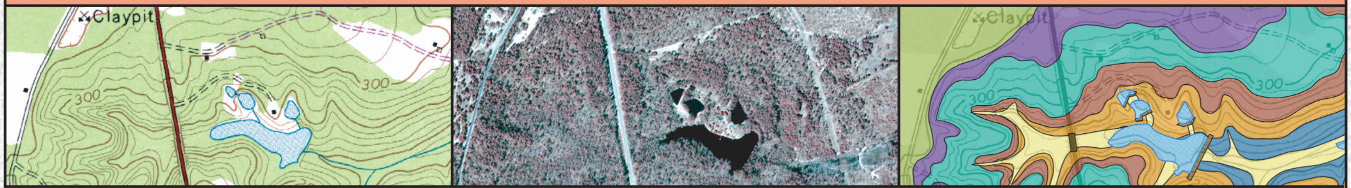
Digital Mapping Techniques ‘11–12



Association of American State Geologists | **United States Geological Survey**

Digital Mapping Techniques ‘11–12 Workshop Proceedings

May 22–25, 2011
Williamsburg, Virginia

DMT’11 hosted by the
Virginia Division of Geology
and Mineral Resources and
The College of William & Mary

May 20–23, 2012
Champaign, Illinois

DMT’12 hosted by the
Illinois State Geological Survey

Convened by the
Association of American State Geologists
and the
U.S. Geological Survey

Open-File Report 2014–1167

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

Digital Mapping Techniques ‘11–12 Workshop Proceedings

Edited by David R. Soller

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2014

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

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Introduction

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It has been my privilege for sixteen years to work with colleagues through the Digital Mapping Techniques (DMT) workshop series. Within the Nation's geological surveys, and in private industry, academia, and agencies both within and beyond the U.S. border, these meetings have had a strong influence on the development of methods, guidelines, and standards for digital geologic mapping, production, and dissemination. Despite the increasing fiscal constraints and workloads in all agencies, colleagues continue to enthusiastically gather together at the DMT meetings, to share their knowledge and experience, and to improve the geoscience community's ability to reach our audiences with high-quality science. The meetings in 2011 and 2012 continued this tradition:

- The Digital Mapping Techniques '11 (DMT'11) workshop was hosted by Virginia Division of Geology and Mineral Resources and The College of William & Mary, and coordinated by the National Geologic Map Database project. Conducted May 22-25 on the campus of The College of William & Mary, in Williamsburg, Virginia, it was attended by 77 technical experts from 30 agencies, universities, and private companies, including representatives from 19 State geological surveys (see "DMT'11 Presentations and Attendees" in these Proceedings).

- The Digital Mapping Techniques '12 (DMT'12) workshop was hosted by the Illinois State Geological Survey and coordinated by the National Geologic Map Database project. Conducted May 20-23 on the campus of The University of Illinois, in Champaign, Illinois, it was attended by 73 technical experts from 34 agencies, universities, and private companies, including representatives from 25 State geological surveys (see "DMT'12 Presentations and Attendees" in these Proceedings).

At these meetings, 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 formats; (5) analytical GIS techniques; and (6) continued development of the National Geologic Map Database.

Throughout the first decade of DMT workshops, the Proceedings (see Appendix) were published in a timely fashion. More recently, however, various factors combined to constrain each author's ability to prepare and publish their written contributions. Further, new (generally Web-based) venues for rapid sharing of information somewhat diminished the need for publication of these Proceedings. Despite this diminishing role for the Proceedings, there remains the enduring need to document our methods, challenges, and accomplishments. And so these Proceedings continue to be published, albeit in a more limited format. I sincerely thank those authors who were able to muster the time and energy to document their presentations herein. For more information and links to presentations and posters given at DMT'11 and '12, I refer you to the list of presentations presented elsewhere in the Proceedings, and to *http://ngmdb.usgs.gov/Info/dmt/DMT11presentations.html* and *http://ngmdb.usgs.gov/Info/dmt/DMT12presentations.html*. I anticipate that Proceedings will be published for subsequent DMT meetings, albeit with changes to the format.

Acknowledgments

The success of these DMT workshops, throughout their sixteen years, has depended on the intellect and enthusiasm of the attendees. I thank them profusely, for without their collegial spirit, the DMT workshop series would have failed long ago. I also, of course, offer my sincere appreciation to our gracious hosts: for DMT'11 – David Spears (Virginia Division of Geology and Mineral Resources) and Chuck Bailey (College of William & Mary), and for DMT'12 – Mark Yacucci and Don McKay (Illinois State Geological Survey). The meetings were expertly managed, conducive to discussion and interaction, and thoroughly enjoyable.

Appendix. Previous Digital Mapping Techniques Workshops

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2009:
Hosted by the West Virginia Geological Survey, in Morgantown, West Virginia, May 10-13, 2009. Almost 90 technical experts from 42 agencies, universities, and private companies attended, including representatives from 24 State geological surveys.

Soller, D.R., ed., 2011, Digital Mapping Techniques '09—Workshop Proceedings: U.S. Geological Survey Open-File Report 2010–1335, 260 p., *http://pubs.usgs.gov/of/2010/1335/*.

2010:
Hosted by the California Geological Survey, in Sacramento, California, May 16-19, 2010. More than 110 technical experts from 40 agencies, universities, and private companies attended, including representatives from 19 state geological surveys.

Soller, D.R., ed., 2012, Digital Mapping Techniques '10—Workshop Proceedings: U.S. Geological Survey Open-File Report 2012–1171, 170 p., available only online at *http://pubs.usgs.gov/of/2012/1171/*.

DMT '11 Presentations and Attendees

Twenty oral and eighteen poster presentations were given, supplemented by Discussion Sessions. These are listed below; please also see *http://ngmdb.usgs.gov/Info/dmt/DMT11presentations.html* for presentations and posters available for download. The meeting was attended by 77 technical experts from 30 agencies, universities, and private companies, including representatives from 19 State geological surveys; the list of attendees is provided below.

Oral Presentations

[listed in order of presentation]

Building the "National Archive" of geologic maps – A progress report on the National Geologic Map Database (NGMDB)
By David R. Soller and Nancy R. Stamm (U.S. Geological Survey)

Challenges in developing three-dimensional geological models at the Kentucky Geological Survey
By William M. Andrews, Jr. (Kentucky Geological Survey)

The Washington State Geologic Interactive Map Portal – A Demonstration
By Anne Olson (Washington State Geological Survey)

Geologic Map Production in NCGMP Databases
By Ryan Clark (Arizona Geological Survey)

Utilizing the NCGMP09 data model in student mapping projects: Advancing the techniques of tomorrow's geologic mappers
By Andrew L. Wunderlich (University of Tennessee – Knoxville)

The National Map and the Geologic Community of Use
By Kent Brown (Utah State Geological Survey), Michael Cooley and Dave Greenlee (U.S. Geological Survey), James Barrett (Enterprise Planning Solutions LLC), and Gregory Allord (U.S. Geological Survey)

Scanning and Georeferencing USGS Historical Topographic Quadrangles
By Gregory Allord (U.S. Geological Survey)

Improving access to the NGMDB's archive of georeferenced geologic maps, via Esri's Image Server
By Christopher P. Garrity, David R. Soller, Mark E. Reidy, Robert S. Wardwell, Justine E. Takacs, and S. Blake Wingfield (U.S. Geological Survey)

Community Maps – Implications for the Geologic Community
By Larry Batten (Esri, Inc.)

Publishing Surficial Geologic Maps of Delaware
By Lillian T. Wang (Delaware Geological Survey)

NPS GRI Development of Digital Geologic Data for use in Google Earth
By Stephanie O'Meara and Jim Chappell (Colorado State University and the National Park Service)

Automation of Google Earth KML Creation and Display of Geologic Data in ArcGIS
By Heather Stanton, Jim Chappell, and Stephanie O'Meara (Colorado State University and the National Park Service)

LiDAR (High Resolution Digital Elevation Data) Acquisition in Virginia
By John Scrivani (Virginia Geographic Information Network (VGIN), Virginia Information Technology Agencies (VITA))

Mapping with Lidar Based DEMs – a Geologist's New Tool
By Thomas G. Whitfield (Pennsylvania Geological Survey)

Confessions of an EDMAP faculty
By Christopher M Bailey (College of William & Mary)

A collaborative prototype multi-level digital geologic map of Virginia using Google Earth
By Owen P. Shufeldt and Steven J. Whitmeyer (James Madison University), and Christopher M. Bailey (College of William & Mary)

Global Data Access for Mining (GDAm) Showcase – A Collaboration Tool Using your Geologic Map Data
By Willy Lynch (Esri)

The Alaska state map; creation of draft units description through the map database
By Frederic H. Wilson and Chad P. Hults (U.S. Geological Survey)

The Nevada Digital Dirt Mapping Experiment: Post-Mortem and Prospects for a Better Approach to Collaborative Geologic Map Development
By Kyle House (U.S. Geological Survey)

Tricks and Tips for Creating a Layered Geo-Enabled Adobe PDF Map
By John Bocan (West Virginia Geological and Economic Survey)

Discussion Sessions

At each DMT meeting, several informal Discussion Sessions are conducted. Some sessions facilitate information exchange on a general topic, such as digital cartography, whereas other sessions are more focused, for example on a proposed plan for standards development. The title and subject of three DMT'11 Discussion Sessions are given below.

(1) "Emerging standards for database design and data exchange – what is appropriate for your agency, your data, and the users of your data?"
Topic Summary – We all collect, manage, or distribute geologic map data. Our work may be facilitated or hindered by geologic map database and data exchange standards and guidelines, which have been under development for many years. The future of our data was discussed – how we create and manage our data. Some organizations have a well-developed and fully functional data model schema and an established workflow. Other agencies are just considering how to develop a data and workflow standard. This discussion focused on the various agency's specific requirements and mission and whether a database design seemed appropriate at this time.
Moderated by Loudon Stanford (Idaho Geological Survey)

(2) "The FGDC Geologic Map Symbolization Standard – What are the next steps?"
Topic Summary – Collaboration between Esri, FGDC, and the NGMDB has resulted in release and subsequent update of a subset of the FGDC symbols, created as Cartographic Representations for use in ArcGIS. Revisions to the Standard, and updates to the Arc implementation, are being considered by the FGDC. In this session, comments and guidance were requested, specifically: (1) whether Arc styles or Cartographic Representations are preferred, or if both are needed now and in the near future, but for different purposes; (2) who can volunteer to help build, or evaluate, the current Esri set and any new symbols created; and (3) the procedure and schedule for revising the Standard, mostly by adding new symbols. Advice from the DMT meeting and elsewhere will be considered in a FGDC plan to be developed in the future.
Session moderated by Dave Soller (FGDC, USGS)

(3) "Cartographic Design & Map Production"
Topic Summary – An informal session on map design and preparation techniques, and publication (traditional and Web). This session offered a mix of short, informal presentations and general discussion on topics raised by the attendees. Two presentations were given by Kent Brown (Utah Geological Survey):

- Raster Blending Techniques and Multi-Image Mashups for GIS
- Creating Slope-Enhanced Shaded Relief Base Maps

Session moderated by Kent Brown (Utah Geological Survey) and Dave Soller (USGS).

Poster Presentations

[listed alphabetically by author]

Final Results from 2010 Digital Field Mapping Technology Survey
By Jennifer E. Athey (Alaska Division of Geological & Geophysical Surveys)

What a Relief! New views on Virginia's physiography
By Christopher M. Bailey and Molly Cox (College of William & Mary)

Tools and Techniques for 3D Visualization of Boreholes and Cross Sections in ArcScene
By Jennifer Carrell (Illinois State Geological Survey)

Inventory Mapping and Characterization of Landslides Using LiDAR: Kenton and Campbell Counties, Kentucky
By Matt Crawford (Kentucky Geological Survey)

Replacing the USGS topographic quadrangle – basemap alternatives for geologic maps
By Jane Johnshoy Domier and Donald E. Luman (Illinois State Geological Survey)

Virginia's Contributions to the National Geothermal Data System
By Chelsea M. Feeney (Virginia Division of Geology and Mineral Resources)

Improving access to the National Geologic Map Database's archive of georeferenced geologic maps, via Esri Image Server
By Christopher P. Garrity, David R. Soller, Mark E. Reidy, Robert S. Wardwell, Justine E. Takacs, and S. Blake Wingfield (U.S. Geological Survey)

Using High-Resolution Digital Terrain Models to Improve Bedrock and Surficial Geologic Mapping in Virginia
By Amy K. Gilmer and Matthew Heller (Virginia Division of Geology and Mineral Resources)

Things You Used to Hate About Map Layout in Arc Have Changed: Attractive and Complete Maps Are Possible in ArcGIS!
By Sarah E. Gooding, Paula J. Hunt, and Philip A. Dinterman (West Virginia Geological and Economic Survey)

Using the Magellan MobileMapper 6 and ArcPad 10 in the Field
By Paula J. Hunt and Philip A. Dinterman (West Virginia Geological and Economic Survey)

The Placitas 7 1/2" Quadrangle, Pitkin County, Colorado – A 3D Geology Map Example Using Esri ArcGIS10
By Willy Lynch (Esri)

Geology and History of an 19th and early 20th Century Industrial Complex:
The Nuttall Mine and Nuttallburg, WV
By Gayle H. McColloch, Jr., and Jane S. McColloch (West Virginia Geological and Economic Survey)

West Virginia Mine Pool Atlas – A Work in Progress
By Jane S. McColloch, Richard D. Binns, Jr., Bascombe M. Blake, Jr., and Gayle H. McColloch, Jr. (West Virginia Geological and Economic Survey)

Mapping Abandoned Mine Using Imagery and Lidar from the Ohio Statewide Imagery Program
By James McDonald (Ohio Geological Survey)

AASG Geothermal Data: State Data in the National Geothermal Data System
By Steve Richard, Ryan Clark, and Lee Allison (Arizona Geological Survey)

Laying the Foundation for a Dynamic Geologic Map of Virginia
By Hannah Shepherd and Amy K. Gilmer (Virginia Division of Geology and Mineral Resources) and Daniel Kestner (Virginia Division of Mined Land Reclamation)

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

Acquisition and Processing Workflow for Geologic Map Images in the National Geologic Map Database (NGMDB) Map Catalog
By Rob Wardwell, David R. Soller, and Christopher P. Garrity (U.S. Geological Survey)

List of Workshop Attendees

[Grouped by affiliation]

Alaska Division of Geological and Geophysical Surveys
Jennifer Athey
James Weakland

Arizona Geological Survey
Ryan Clark
Stephen Richard

College of William & Mary
Chuck Bailey
Karen Berquist
Rachel Martin

Colorado State University / National Park Service
James Chappell
Stephanie O'Meara
Heather Stanton
Trista Thornberry-Ehrlich

Delaware Geological Survey
Lillian Wang

Esri, Inc.
Larry Batten
Willy Lynch

Idaho Geological Survey
Loudon Stanford

Illinois State Geological Survey
Jennifer Carrell
Jane Domier

James Madison University
Owen Shufeldt
Steve Whitmeyer

Kansas Geological Survey
John Dunham

Kentucky Geological Survey
William Andrews

Montana Bureau of Mines and Geology
Katie McDonald

Natural Resources Canada-Geological Survey of Canada
Vic Dohar
David Everett
Dan Kerr

Nevada Bureau of Mines and Geology
Jennifer Mauldin
Matthew Richardson

New Hampshire Geological Survey
Rick Chormann

New Mexico Bureau of Geology and Mineral Resources
J. Michael Timmons

Ohio Geological Survey
James McDonald

Pennsylvania Geological Survey
Thomas Whitfield

Pennsylvania State University
Jay Parrish

South Carolina Geological Survey
Erin Koch

U.S. Department of Agriculture
Jerry Bernard

U.S. Geological Survey
Greg Allord
Michael Cooley
Allen Crider
Mary DiGiacomo-Cohen
Joseph East
Chris Garrity
Ralph Haugerud
Kyle House
Linda Jacobsen
Linda Masonic
Gary Nobles
Randall Orndorff
Lydia Quintana
Mark Reidy
Steve Schindler
David Soller
Nancy Stamm
Will Stettner
Rob Wardwell
Frederic Wilson

University of Alabama
Douglas Behm

University of Tennessee
Andrew Wunderlich

Utah Geological Survey
Kent Brown

Virginia Division of Geology and Mineral Resources
Rick Berquist
Elizabeth Campbell
Lorrie Coiner
Chelsea Feeney
Dennis Feeney
Amy Gilmer
Matt Heller
Hannah Shepherd
David Spears

Virginia Information Technologies Agency
Scrivani, John

Washington State Department of Natural Resources
Anne Olson

West Virginia Geological and Economic Survey
John Bocan
Philip Dinterman
Sarah Gooding
Paula Hunt
Gayle McColloch
Jane McColloch

Wyoming State Geological Survey
Suzanne Luhr
Fred McLaughlin
Phyllis Ranz

DMT '12 Presentations and Attendees

Nineteen oral and seventeen poster presentations were given, supplemented by Discussion Sessions. These are listed below; please also see *http://ngmdb.usgs.gov/Info/dmt/DMT12presentations.html* for presentations and posters available for download. The meeting was attended by 73 technical experts from 34 agencies, universities, and private companies, including representatives from 25 State geological surveys; the list of attendees is provided below.

Oral Presentations

[listed in order of presentation]

Building the "National Archive" of geologic maps – A progress report on the National Geologic Map Database (NGMDB)
By National Geologic Map Database project (Dave Soller, presenter, U.S. Geological Survey)

Evolution of web mapping applications at Alaska's geological survey as of 2012
By Jennifer E. Athey, Christopher D. Ramey, and James R. Weakland (Alaska Division of Geological & Geophysical Surveys), Will H. Fisher (Geographic Information Network of Alaska), and Kenneth A. Woods and Susan S. Seitz (Alaska Division of Geological & Geophysical Surveys)

Planning a (digital) geologic mapping data migration pilot project – Embarking on a journey toward standardization
By Meredith C. Payne (Washington State Department of Natural Resources, Division of Geology and Earth Resources)

Progress report on NCGMP09
By Ralph A. Haugerud and David R. Soller (U.S. Geological Survey), Stephen M. Richard (Arizona Geological Survey), and Evan E. Thoms (U.S. Geological Survey)

Online Geologic Maps: A Simple Application for Publishing NCGMP09 Databases
By Ryan Clark (Arizona Geological Survey)

NCGMP through the Data Preservation Lens: Preparing for the future by digging into the past
By Janel Day (Arizona Geological Survey)

The AAPGF-OSU Geoscience GIS Consortium and Funding Opportunities
By Christina Hall (AAPG Datapages) and April Chipman (Oklahoma State University)

USGS Historical Topographic Map Collection
By Gregory Allord (U.S. Geological Survey)

National Enhanced Elevation Assessment and Program Proposal
By Larry Sugarbaker (U.S. Geological Survey)

Illinois Height Modernization Program: Data Stewardship for High Resolution Elevation Data
By Sheena Beaverson (Illinois State Geological Survey), Amy J. Eller (Illinois Department of Transportation), and Donald E. Luman, Deette M. Lund, and Michael E. Blumhoff (Illinois State Geological Survey)

Making the US Topo – A Process Discussion
By Bob Davis (U.S. Geological Survey)

Cartographic issues and concerns in 3-D geologic mapping
By Don Keefer, Jason Thomason, and Jennifer Carrell (Illinois State Geological Survey)

Managing Complex Schema Upgrades with FME and Arc
By Richard Nairn (Geological Survey of Canada)

Workflow methodology for 3-Dimensional geologic modeling with examples from structural characterization of geothermal systems
By Nicholas H. Hinz, Drew L. Siler, James E. Faulds, and Brett Mayhew (Nevada Bureau of Mines and Geology)

Ganfeld supporting tools for Field Data Management
By Pierre Brouillette, Étienne Girard, Gabriel Huot-Vézina, Stephen Williams, and Patty Zhao (Geological Survey of Canada)

Geolex tricky bits
By National Geologic Map Database project (Nancy Stamm, presenter, U.S. Geological Survey)

What's New from Esri & ArcGIS 10.1 for Authoring, Publishing, and Sharing Maps for the DMT Community
By Larry Batten and Willy Lynch (Esri)

GeoWebFace – Online, Geological and Oil & Gas maps and data for Michigan
By John M. Esch and Steven E. Wilson (Michigan Department of Environmental Quality), and Ron Thomas, Scott Reynolds, and Gary Taylor (Michigan Department of Technology, Management and Budget)

From data collection to rolling out products: considerations and workflows when developing 3-D geologic maps
By Don Keefer, Jason Thomason, and Steve Brown (Illinois State Geological Survey)

Discussion Sessions

At each DMT meeting, several informal Discussion Sessions are conducted. Some sessions facilitate information exchange on a general topic, such as digital cartography, whereas other sessions are more focused, for example on a proposed plan for standards development. The title and subject of the two focused DMT'12 Discussion Sessions are given below.

(1) "Content and Data Structure for 3D geologic maps"
Topic Summary – a general-information session, intended to contribute to some convergence of thought on how data are managed. The focus was toward:

- What types of content are common in our 3D databases? Which are free text, which are standardized?

- How do we publish and archive 3D data? Methods, formats, and so forth.

Moderated by Don Keefer (Illinois State Geological Survey), William Andrews (Kentucky Geological Survey), and Dave Soller (U.S. Geological Survey)

(2) "US Topo and its applications to geologic map cartography and GIS"
This session included short presentations by:
- Tracy Fuller (U.S. Geological Survey)
- Don Luman (Illinois State Geological Survey)
- Jane Johnshoy Domier (Illinois State Geological Survey)
- Kent Brown (Utah Geological Survey)
- Bob Davis (U.S. Geological Survey)

Poster Presentations

[listed alphabetically by author]

The Geologic Time Scale – Illinois' Geologic History
By Curt Abert (Illinois State Geological Survey)

History and status of 2D and 3D geologic mapping at the Kentucky Geological Survey
By William M. Andrews, Jr. (Kentucky Geological Survey)

Moving toward a new geologic map database standard, NCGMP: the good, the bad and the ugly
By Janel Day (Arizona Geological Survey)

Accessing the National Geologic Map Database (NGMDB) Map Catalog via ArcGIS Image Server
By Christopher P. Garrity and David R. Soller (U.S. Geological Survey)

Migrating Abandoned Underground Mine Applications to ArcGIS Add-ins
By Robert H. Hanover and James McDonald (Ohio Geological Survey)

Better geologic maps with lidar
By Ralph A. Haugerud, R.W. Tabor, and R.E. Wells (U.S. Geological Survey)

Studies in the Mahomet Valley
By A.M.A. Ismail and A.J. Stumph (Illinois State Geological Survey)

LiDAR Landscapes of Illinois
By Jane E. Johnshoy Domier and Donald E. Luman (Illinois State Geological Survey)

Presentation/Discussions in the ISGS Earth Systems Visualization Laboratory
By Don Keefer and Jason Thomason (Illinois State Geological Survey)

Migrating Ohio's Geology GIS datasets to the new NCGMP09 Standard – Progress Report
By James McDonald and Joseph G. Wells (Ohio Geological Survey)

Vector, Raster, and 3D: 'Maps' for the Middle Illinois River Valley
By E.D. McKay, III, Richard Berg, and Barbara Stiff (Illinois State Geological Survey)

Managing Complex Schema Upgrades with FME and Arc
By Richard Nairn (Geological Survey of Canada)

Communicating a Digital Geologic Map in the Digital World
By Stephanie O'Meara, Jim Chappell, Ron Karpilo, and Georgia Hybels (Colorado State University and National Park Service Geologic Resources Division)

Tablet-based Groundtruthing: Windows (TM) in the field
By Larry Robinson, Andrew Strassman, and Tim Fox (U.S. Geological Survey)

Terrestrial Lidar and Bathymetric Data Integration and Potential Application for the Upper Mississippi River
By Jason J. Rohweder, James T. Rogala, Joseph W. Jakusz, Jenny L. Hanson, Larry R. Robinson, and J.C. Nelson (U.S. Geological Survey)

Database for USGS Map I-1970 – Map Showing the Thickness and Character of Quaternary Sediments in the Glaciated United States East of the Rocky Mountains
By David R. Soller, Patricia H. Packard, and Christopher P. Garrity (U.S. Geological Survey)

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

List of Workshop Attendees

[Grouped by affiliation]

Alaska Division of Geological and Geophysical Surveys
Jennifer Athey
James Weakland

American Association of Petroleum Geologists
Christina Hall

Arizona Geological Survey
Ryan Clark
Janel Day

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

Conservation and Survey Division, University of Nebraska – Lincoln
Les Howard

Delaware Geological Survey
William Schenck

Esri
Larry Batten
Willy Lynch

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Publishing Surficial Geologic Maps of Delaware

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Abstract

The Delaware Geological Survey (DGS) geologic map series began in 1970. Map publications were compiled by an outside vendor with DGS providing text and hand-drawn illustrations. As the DGS entered the 21st century, a gradual transition toward digital mapping began. A full-time position was created to maintain a geographic information system (GIS) and produce publication-quality maps and illustrations. During the transitional period (2000 to 2003), the DGS began to deliver digital data to a vendor, who produced the finished map product. By 2005, the DGS had the ability to create an entire digital map publication in-house. The final layout is created in Adobe Illustrator, and a digital file is delivered to the vendor for printing paper maps. This workflow has resulted in significant time and cost reduction, and discussions of discontinuing printing paper maps to further reduce publication costs are ongoing. A downloadable PDF copy of the map and associated digital data are also available on the DGS website (DGS, 2011a).

Base Map Layers

Earlier DGS geologic maps used the U.S. Geological Survey (USGS) topographic map as the base layer. USGS discontinued updating these layers for Delaware in 1993, requiring a search for other base map options during the transitional period. During this time, a pilot project for the USGS National Map was being developed called the Delaware Data and Mapping Integration Laboratory (DataMIL, 2011). DataMIL provided a crowdsourcing digital update tool for the major layers found on a USGS topographic map. Later, these same layers were also adopted by Delaware as the State's Spatial Data Framework Layers, or base map geographic datasets. The framework layers selected as the necessary base map layers and extracted from DataMIL include boundaries, water features, transportation, and elevation. These data layers were symbolized to mimic original USGS topographic maps using the digital cartographic standard for geologic map symbolization developed by the Federal Geographic Data Committee (FGDC) Geologic Data Subcommittee (FGDC, 2006). The Geologic Data Subcommittee Web site includes a PostScript format for use in Illustrator and other graphic design software (USGS, 2006).

The most challenging dataset to work with was Delaware's elevation layer. This layer consists of 2-foot (ft) contours that were generated from 2005 to 2007 LiDAR data. High-resolution data are beneficial for research purposes, but are a cartographic challenge to present on a smaller scale map. Showing 50- or 100-ft contour intervals on a 1:100,000-scale map was reasonable for the Piedmont area in northernmost Delaware, but was not effective or possible for the majority of the State, which lies within the Atlantic Coastal Plain (fig. 1). Therefore, in lieu of using contours, a shaded relief image constructed from a digital elevation model (DEM) is displayed on DGS countywide 1:100,000-scale maps to show elevation as it relates to the underlying geology. Elevation data on the larger scale, 1:24,000-scale maps use this shaded relief image but also include the 10-ft index and 6-ft intermediate contour intervals. Contours are simplified by removing 75 to 85 percent of the vector points to reduce pixelation and thereby smooth the lines.

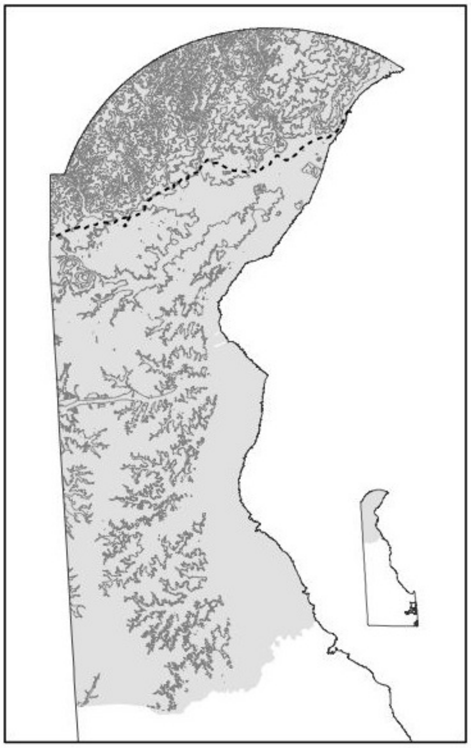

Figure 1. New Castle County, Delaware, with 50-ft contour intervals from 2007 LiDAR data. Dashed line indicates the Fall Zone, which divides the Piedmont (to the north) and Coastal Plain (to the south).

Geologic Mapping

Boring, well, and hand auger data are used in describing geologic formations in the shallow subsurface and at the land surface. DEM data have been used to assist in identifying periglacial and other types of geomorphic features. These data are subjected to cartographic enhancement techniques such as the Swiss Hillshade (shaded relief) method (Esri Mapping Center, 2007), which utilizes the ArcGIS Spatial Analyst extension to vertically exaggerate DEM datasets and accentuate geomorphic features in the relatively flat Coastal Plain areas. Figure 2 shows an area where dune deposits were enhanced with the Swiss Hillshade method, because the DEM shaded relief alone did not highlight these features.

Although the DGS edits and finalizes a geologic map in digital format, the geology contact lines are still hand drafted on a 1:24,000-scale paper map. The drafted map consists of well and hand-auger point locations, the surrounding surficial geology, elevation contours, roads, water features, and surface cover from Delaware's most recent land-use and land-cover data. When the geologist is satisfied with the lines, the map is scanned as a digital image. The next step is to georeference the image and heads-up digitize the geology as polygons in ArcMap. The geology polygon layer is exported from ArcMap at 1:24,000-scale to Adobe Illustrator file format (.ai). The roads layer is used to correctly align any digital layers imported into Illustrator separately.

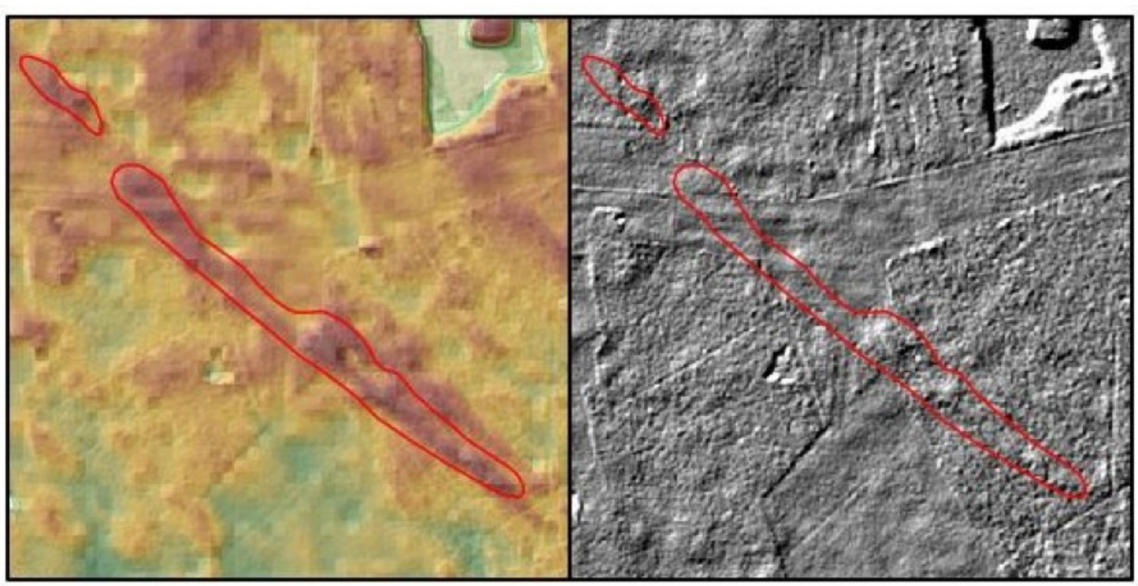

Figure 2. Area where dune deposits are enhanced with the Swiss Hillshade method (left). In the unenhanced DEM shaded relief (right), these features are not readily seen.

Cross Sections

Cross-section illustrations also were hand drawn until DGS transitioned to digital mapping. Creating a digital cross section requires a combination of different software packages and file formats. The geologist selects well and soil-auger boring locations from the DGS Oracle database. A data table of well and boring identifiers and their corresponding x- and y-coordinates then are plotted in ArcMap. These point locations and a DEM are used in the ArcGIS 3D Analyst extension to create an elevation profile graph. Data from the profile are exported to a data table, which contains distance and elevation values. This data table is used in Grapher (Golden Software, *http://www.goldensoftware.com*) to create a digital sketch of a cross section. This basic sketch is exported to Illustrator for publication-quality modifications. Geophysical logs that have been digitized separately are easily incorporated with corresponding wells on the final cross section (fig. 3).

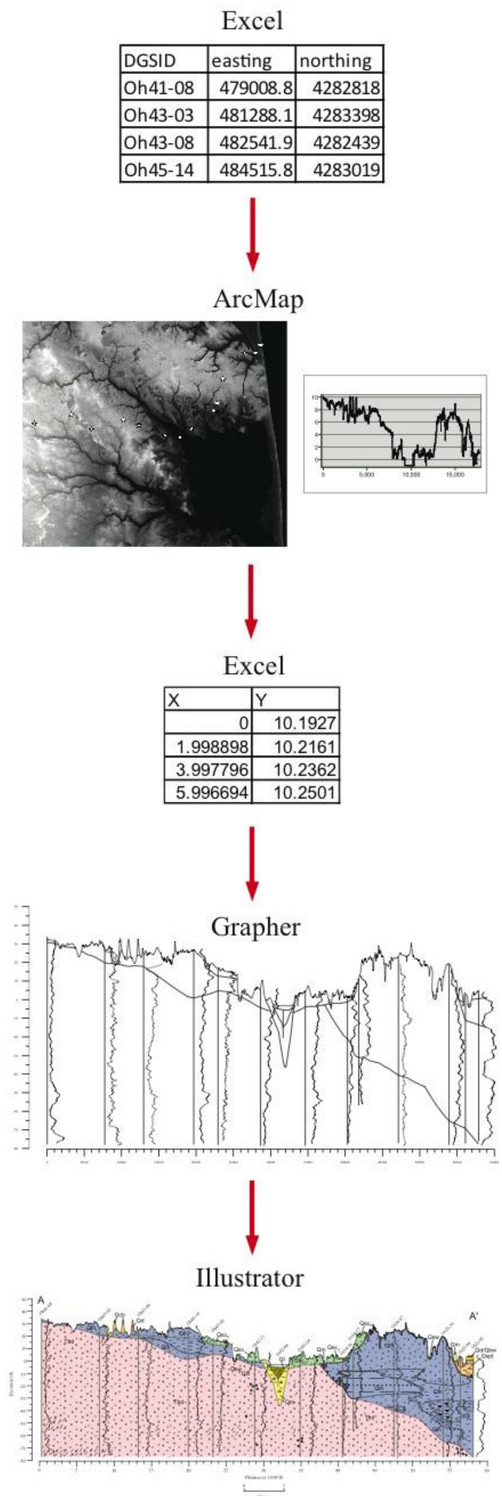

Figure 3. Illustrations of steps and software used to create digital cross sections for DGS geologic map publications.

Offshore Deposits

Large-scale DGS map publication areas are defined by USGS 7.5-minute quadrangle boundaries. Geologic maps that contain portions of the Delaware Bay and Atlantic Ocean included bottom sediment texture descriptions in these offshore areas. Grab sample data used for this interpretation were from various University of Delaware unpublished Master's and Ph.D. theses and dissertations. Since southeastern Delaware quadrangles along the Atlantic Ocean contain 50 percent or more offshore area, discussions arose whether to use these traditional boundaries. It was decided to continue publishing surficial geology by quadrangle for continuity with previous geologic map publications. This decision gave DGS an opportunity to utilize an additional DGS data source, the Delaware Offshore Geologic Inventory (DOGI) (DGS, 2011b). DOGI tracks sediment samples, radiocarbon and amino acid racemization dates, seismic profiles, and vibracores taken from the nearshore and Inner Continental Shelf in State and Federal waters. In 2011, an offshore cross section was used to further define areas as named deposits with detailed descriptions (Ramsey, 2011). These additional data allowed for the boundaries of offshore formation extensions to be generally outlined in relation to the onshore geomorphology. Paleovalleys, interfluves, and ancient offshore features are also identified in this manner.

Summary

In recent years, there has been a major shift at the DGS with both the map printing process and amount of work involved in publishing surficial geologic maps. Map production gradually evolved from manual to digital techniques, and the majority of the workload switched from outside DGS to within the office. The publication review process is expedited at a faster pace with the ability to create and edit maps in-house. This shift has resulted in efficient and cost-effective changes to disseminating Delaware earth science information to Delaware's stakeholders.

References

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DGS, 2011b, Delaware Offshore Geologic Inventory (Web site): The Delaware Geological Survey, accessed December 8, 2011, at *http://www.dgs.udel.edu/projects/delaware-offshore-geologic-inventory*.

Esri Mapping Center, 2007, Esri Mapping Center – Ask a Cartographer, accessed December 8, 2011, at *http://mappingcenter.esri.com/index.cfm?fa=ask.answers&q=21*.

FGDC [prepared for the FGDC by the USGS], 2006, FGDC Digital Cartographic Standard for Geologic Map Symbolization: Reston, Va., FGDC Document Number FGDC-STD-013-2006, 290 p., 2 plates, accessed December 8, 2011, at *http://ngmdb.usgs.gov/fgdc_gds/geolsymstd.php*.

Ramsey, K.W., 2011, Geologic map of the Fairmount and Rehoboth Beach Quadrangles, Delaware: Delaware Geological Survey Geologic Map Series No. 16, scale 1:24,000, accessed December 8, 2011, at *http://ngmdb.usgs.gov/Prodesc/proddesc_95103.htm*.

U.S. Geological Survey (USGS), 2006, FGDC digital cartographic standard for geologic map symbolization (PostScript implementation): U.S. Geological Survey Techniques and Methods 11–A2, accessed December 8, 2011, at *http://pubs.usgs.gov/tm/2006/11A02*.

Illinois Height Modernization Program: Data Stewardship for High Resolution Elevation Data

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The purpose of the Illinois Height Modernization Program (ILHMP) is to improve access to elevation information for Illinois by providing a repository for high-resolution elevation Light Detection and Ranging (LiDAR) data and installing an extensive network of surveying benchmarks. To date, ILHMP has provided access to LiDAR and related derivative elevation data for 22 Illinois counties and added 301 current monument records to the National Spatial Reference System database. New funding will enable a significant program expansion in 2012. We anticipate delivery of LiDAR data for 50 additional counties, including 3 counties acquired with program funding (fig. 1).

The geodetic leveling effort aims to replace lost benchmarks, establish the first north-south geodetic level line in Illinois (fig. 2), and resolve issues related to conversion between numerous vertical datums. Ultimately, the resulting statewide network will consist of points that are Global Positioning System (GPS) accessible, accurate both horizontally and vertically, and tied to a single vertical datum. Height modernization will standardize control used in the measurement and modeling of watersheds, rivers, roadways, floodplains, farm fields, landforms, landslides, and well locations throughout the State. These improvements will result in significant cost savings for public services and infrastructure.

Program information and current status maps are available through the Illinois Natural Resources Geospatial Data Clearinghouse (see *http://crystal.isgs.uiuc.edu/nsdihome/webdocs/ilhmp/*).

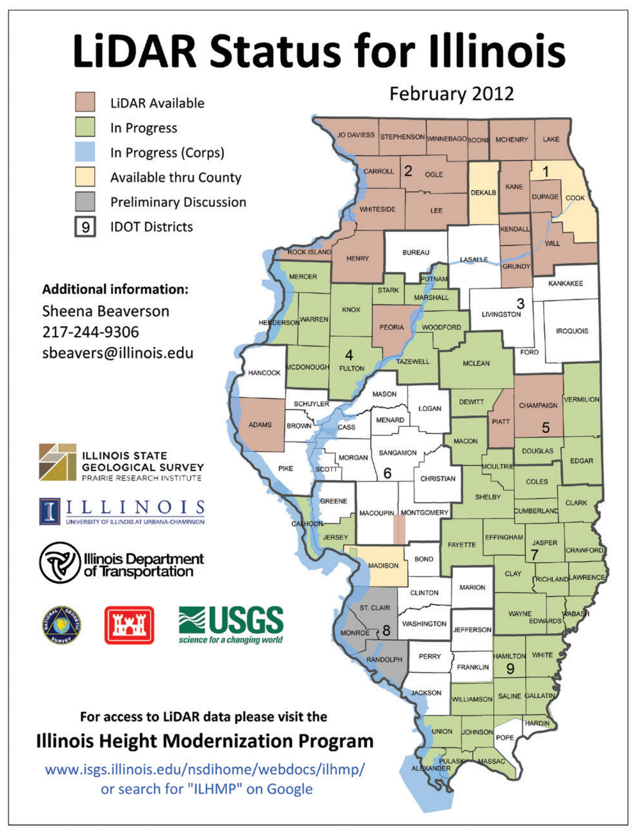

Figure 1. LiDAR status for Illinois as of February 2012.

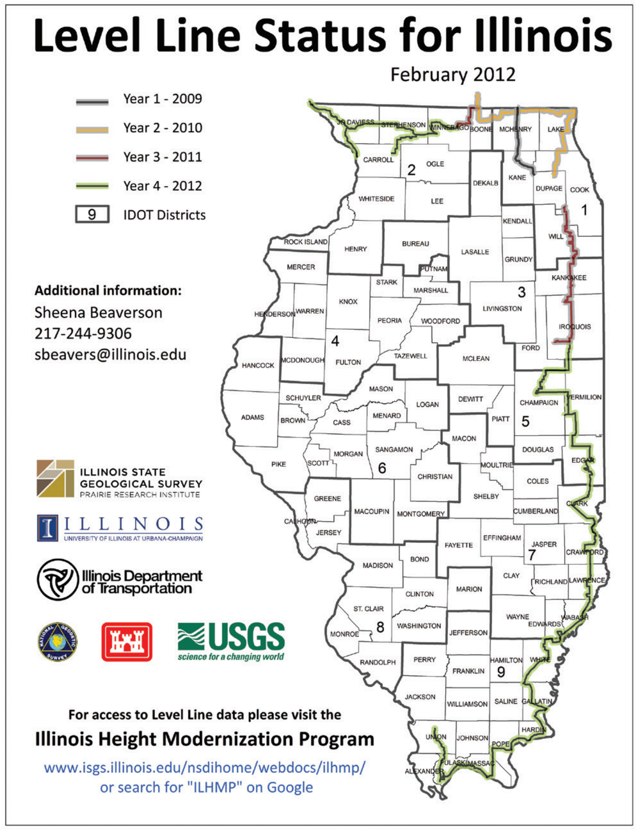

Figure 2. Geodetic level line status for Illinois as of February 2012.

Tools and Techniques for 3D Geologic Mapping in ArcScene: Boreholes, Cross Sections, and Block Diagrams

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Introduction

In the life cycle of a geologic mapping project, a geologist is likely to use five or more different software packages, such as borehole logging programs (WellCAD, LogPlot), database programs (Microsoft Access, Oracle), GIS programs (ArcGIS), specialized modeling software (RockWorks, Surfer, gOcad, GSI3D), and Web-based tools (Google Maps/Earth, Microsoft Virtual Earth). In addition to these programs, graphics programs, such as Adobe Illustrator, Photoshop, and InDesign, are used for cartographic and production work.

Although there is some overlap in functionality among software packages, there is currently no one-stop solution for geologic mapping. For a given task in the mapping process, one program might be better suited than others. The choice of software is often a matter of personal preference and convenience as well as functionality.

This paper, based on a poster presented at the 2011 DMT Workshop, focuses on the functionality of Esri's ArcScene for 3D mapping. I discuss techniques for creating and editing 3D boreholes and cross sections using custom tools as well as out-of-the-box functionality in ArcScene 10. Examples from mapping projects at the Illinois State Geological Survey (ISGS) illustrate how these are used in the mapping workflow. The customization of ArcScene with Visual Basic for Applications (VBA) has played a key role in making ArcScene efficient and practical for geologic mapping.

Advantages of ArcScene

- The interactive 3D environment that ArcScene provides is useful for helping us visualize and understand geologic relations in the subsurface.
- The 3D navigation tools are relatively intuitive and easy to use.
- With ArcScene, users can take advantage of existing data storage formats and workflows already developed for ArcGIS without having to convert data.
- Data in a stand-alone Access database can be read or imported with minimal processing.
- Multiple options exist for customizing and automating tasks: Geoprocessor scripting with Python, Add-ins with ArcObjects, and Model Builder.
- Help and information about customization techniques are well documented by Esri and an active user community.

Limitations of ArcScene

- Texture mapping of vertical surfaces, for example draping an image of a cross section on a vertical wall, is problematic. ArcScene still seems to have trouble with vertical surfaces in general.
- When dealing with the large volumes of data often required by geologic mapping, memory can get used up quickly, causing slow performance and hang-ups. The workaround has been to divide data into smaller geographic areas.
- In ArcScene 10, new 3D geoprocessing tools might work for simple multipatches representing buildings, but they tend to crash when 3D geologic volumes are input.

- Anything beyond simple layer-cake modeling requires some level of customization to make the multistep workflows manageable.
- Custom tools developed over the past 4 years with VBA now need to be rewritten because VBA will be not be supported in future releases of ArcGIS.
- There is still no labeling functionality in ArcScene.
- The new out-of-the-box 3D geometry-editing capabilities touted by Esri are still limited and do not always work, especially with the vertical surfaces of boreholes and cross sections. Digitizing in 3D space requires you to snap new features to existing data layers; however, you cannot snap to the face of a vertical areal feature such as a cross section wall.
- The geometry of complex multipatches, such as those generated by extruded surfaces, cannot be edited.

Xacto Section Tools

Visual Basic for Applications (VBA) was used to develop a cross section tool called Xacto Section within ArcMap (figs. 1 and 2). The tool generates a 2D cross-section profile as a collection of polyline and point shapefiles. The shapefiles can be digitally edited in ArcMap and (or) exported to Adobe Illustrator for finishing. Completed cross sections also can be exported as true 3D vector features for viewing and editing in ArcScene (fig. 3). One of the advantages of this program is that the output features have a spatial reference, meaning that, when the map document is set to the desired map scale, the cross-section measurements will always be correct.

In addition to creating cross sections from scratch, the tool can be used in combination with the MaPublisher plug-in for Illustrator to convert legacy cross-section vector graphics into 3D georeferenced shapefiles (fig. 4). In this way simple "spaghetti" graphics can be restored to valuable quantitative geologic data.

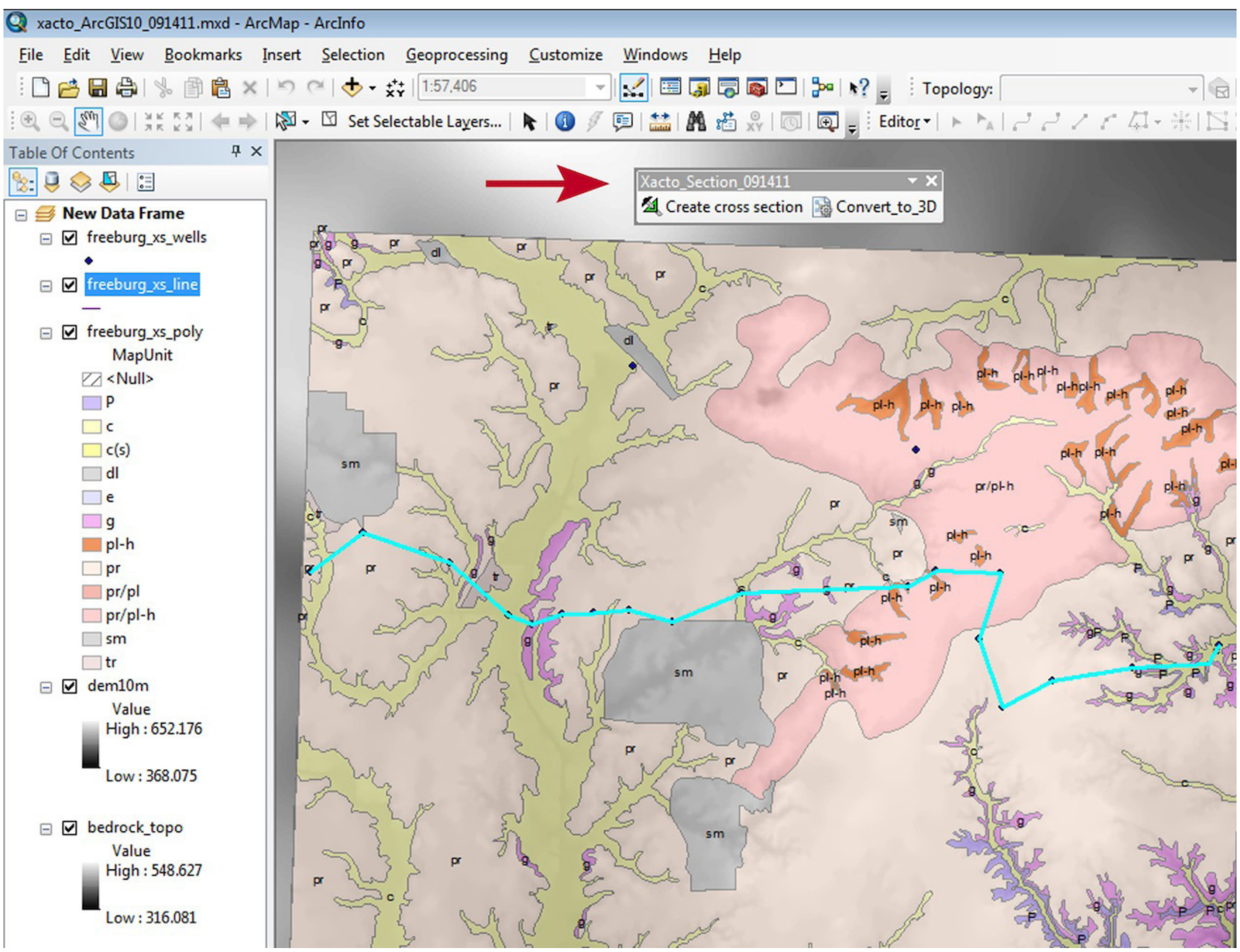


Figure 1. The Xacto Section toolbar in an example ArcMap document. The blue line represents a cross section drawn with this tool.

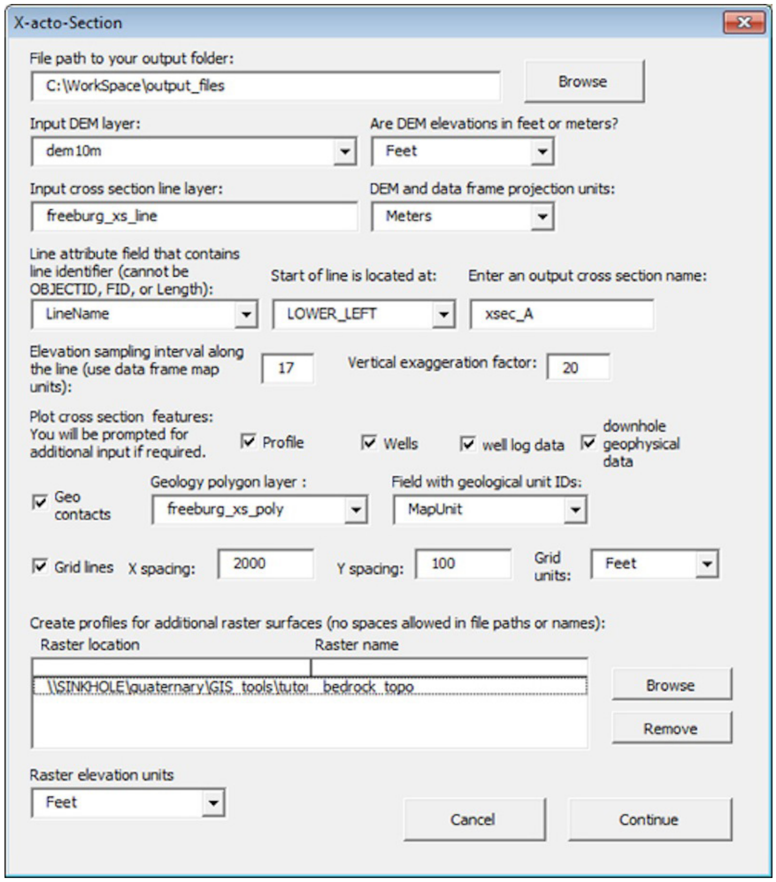


Figure 2. The input form for creating 2D cross sections.

The ArcMap document (.mxd) containing the Xacto toolbar is available on the ArcGIS Resources Web site: *http://resources.arcgis.com/gallery/file/geoprocessing/details?entryID=C83CC388-1422-2418-7F10-B4D3DF5F1EE6*. The various data types that Xacto can manipulate and output are provided below.

Program Inputs

- Elevation raster (Esri Grid)
- Cross-section line
- Geology polygons
- Well and boring points
- Additional subsurface rasters
- Well log data table (.dbf)

Output 2D Shapefiles

- Surface profile line, split at contact points
- Geologic contact points on the land surface
- Well and boring points
- Wells extruded as lines into the subsurface, coded with geological attributes
- Additional subsurface profiles

Output 3D Shapefiles

- 3D features can be symbolized and attributed with standard editing tools in ArcScene 10.

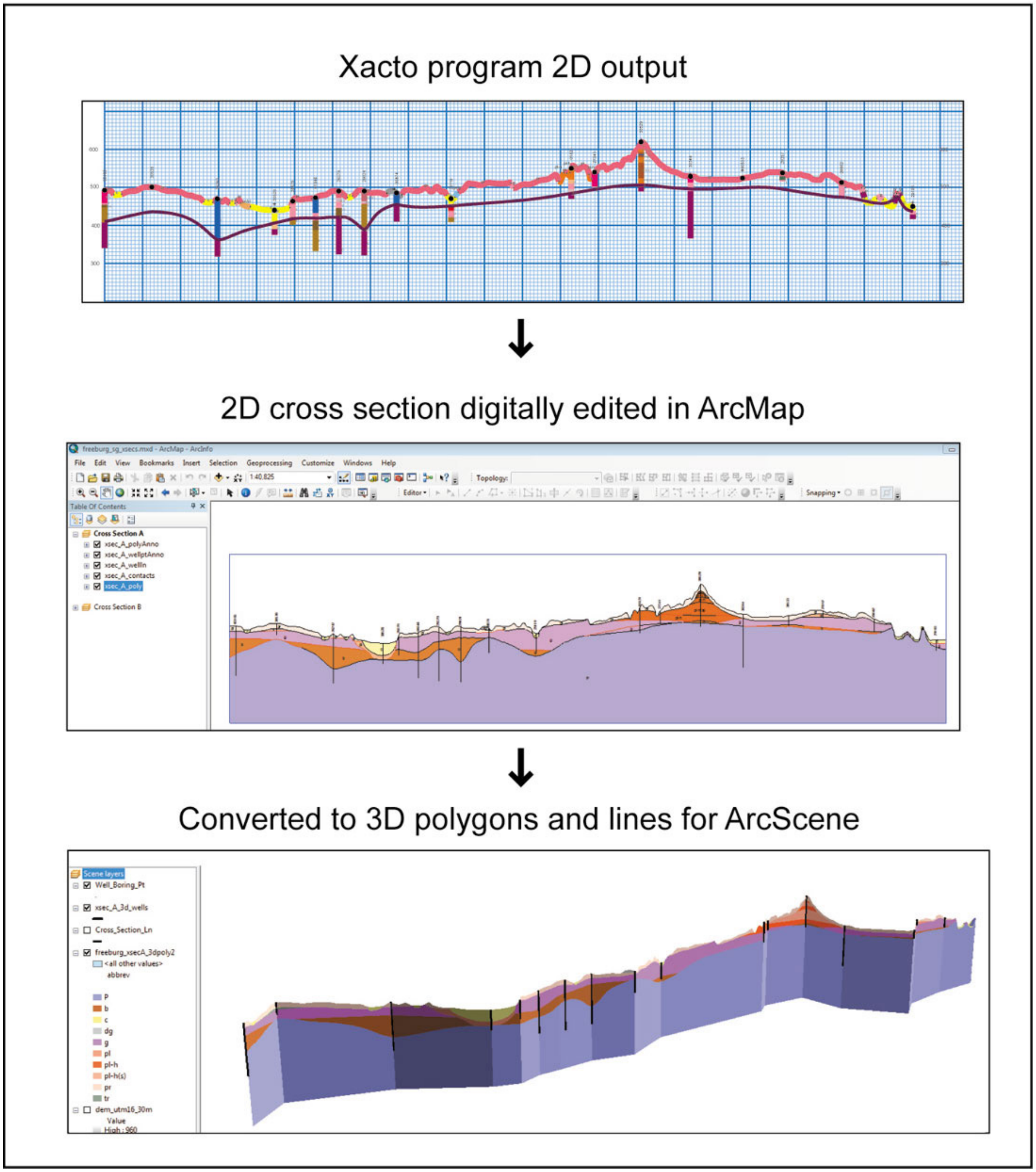


Figure 3. The output 2D cross-section profile can be edited in ArcMap and converted into a 3D shapefile for displaying in ArcScene.

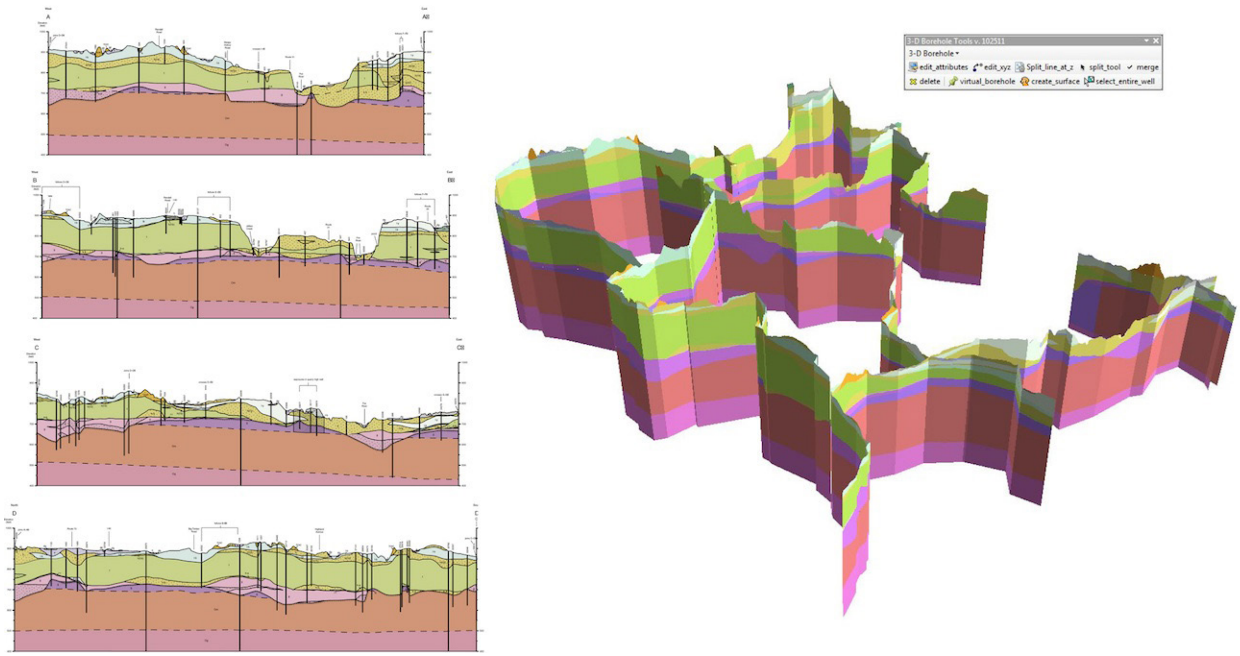


Figure 4. 2D cross-section graphics from older maps can be georeferenced with MaPublisher in Adobe Illustrator, thus enabling the graphics to be converted into 3D cross sections in ArcMap.

3D Borehole Tools

The ability to view, zoom, rotate, and fly through borehole data in three dimensions is vital to understanding geological relations in the subsurface. ArcScene provides a relatively easy and familiar interface for these tasks. A limitation, however, has been that prior to ArcGIS 10, editing tools were not available in ArcScene. VBA was used to develop a custom tool bar in ArcScene, called 3D Borehole Tools (fig. 5). The tool bar contains 14 tools that allow the user to create 3D borehole features from tabular log data, edit the geometry and attributes of those features, and quickly create surfaces from queried borehole intervals (fig. 6). Geophysical log data as .LAS-formatted text files can also be plotted as graphs along corresponding boreholes. The tools are available for download at *http://resources.arcgis.com/gallery/file/geoprocessing/details?entryID=3CB0669C-1422-2418-7F29-072DB9AA0AE3*. Some of the highlights of the 3D Borehole Tools include the following:

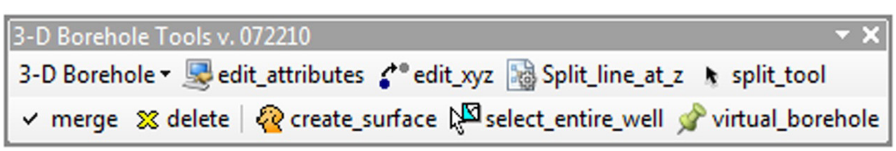


Figure 5. The 3D Borehole Toolbar in ArcScene.

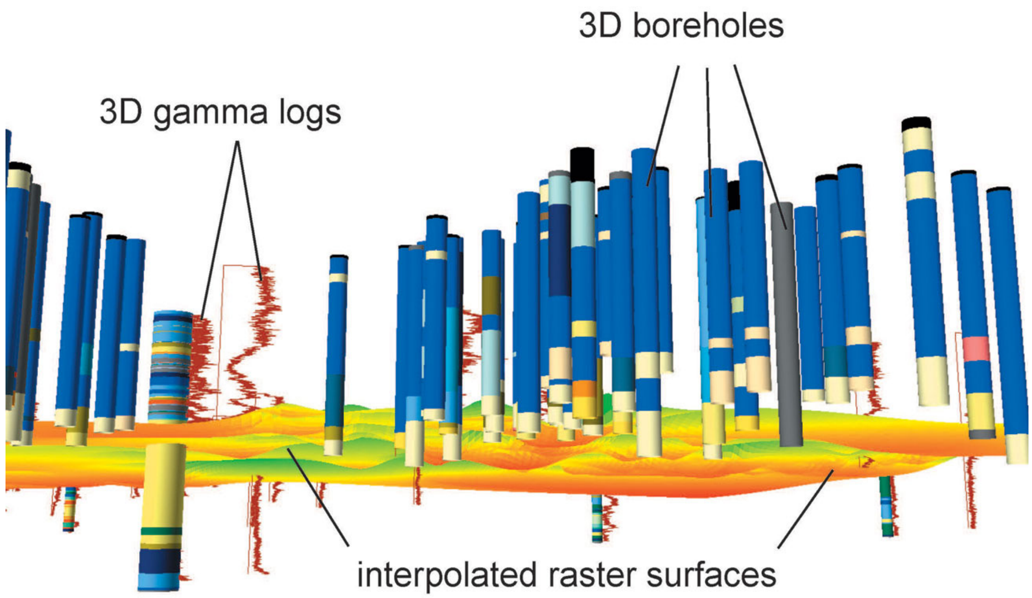


Figure 6. A 3D scene from ArcScene shows borehole lines symbolized as tubes, geophysical log graphs as 3D lines, and raster surfaces interpolated from user-selected borehole segments.

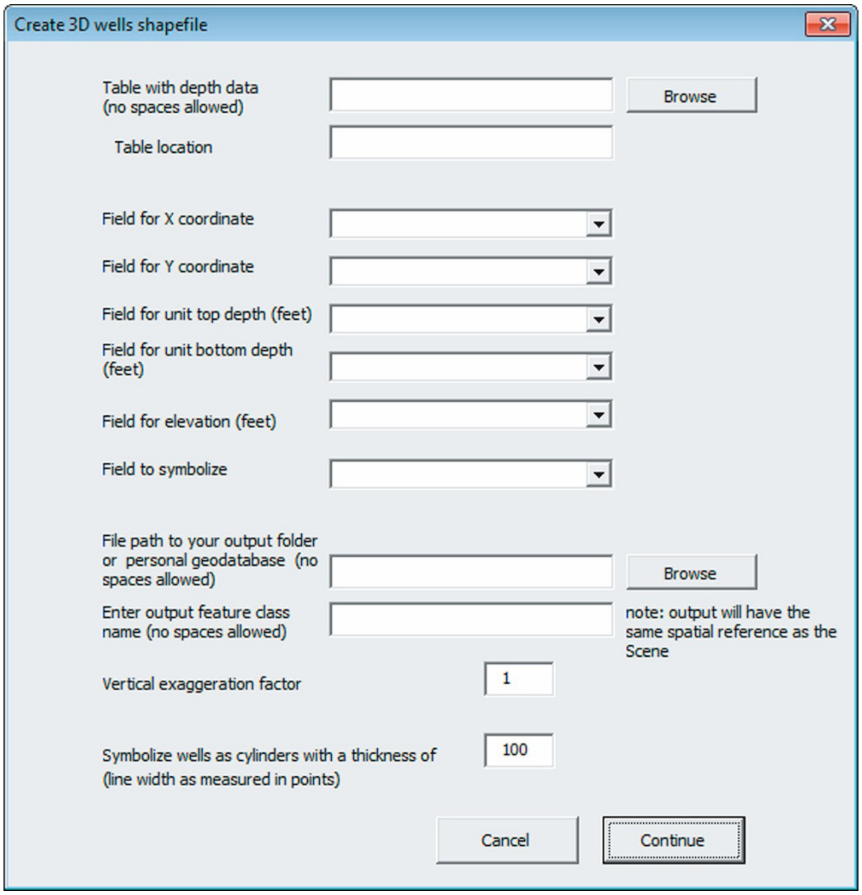


Figure 7. The input form for creating 3D boreholes.

Create_3d_lines

This tool (fig. 7) takes as input a .dbf or geodatabase table of well log data with fields for X, Y, well elevation, top depths, bottom depths, and geologic units (fig. 8). The output is a 3D polyline shapefile. The tool automatically symbolizes the lines as 3D cylinders. When dealing with several thousand borehole segments, rendering performance can be increased by converting the 3D lines into multipatches, though the ability to edit the feature geometry will be lost.

Plot_gamma

This tool reads geophysical logs (figs. 9 and 10) from a designated folder. For each log file, the program plots a graph alongside the borehole whose ID matches the log file name. The output is a 3D line shapefile.

Create surface

This tool provides a quick interface to the ArcGIS Topo to Raster interpolation tool. The tool automatically extracts either the top or bottom point of each selected borehole segment and feeds it into the Topo to Raster tool. The output raster is automatically symbolized with a default color ramp, and base heights are automatically applied to the layer. This tool is useful for creating exploratory test surface patches in the process of interpreting and reclassifying borehole data.

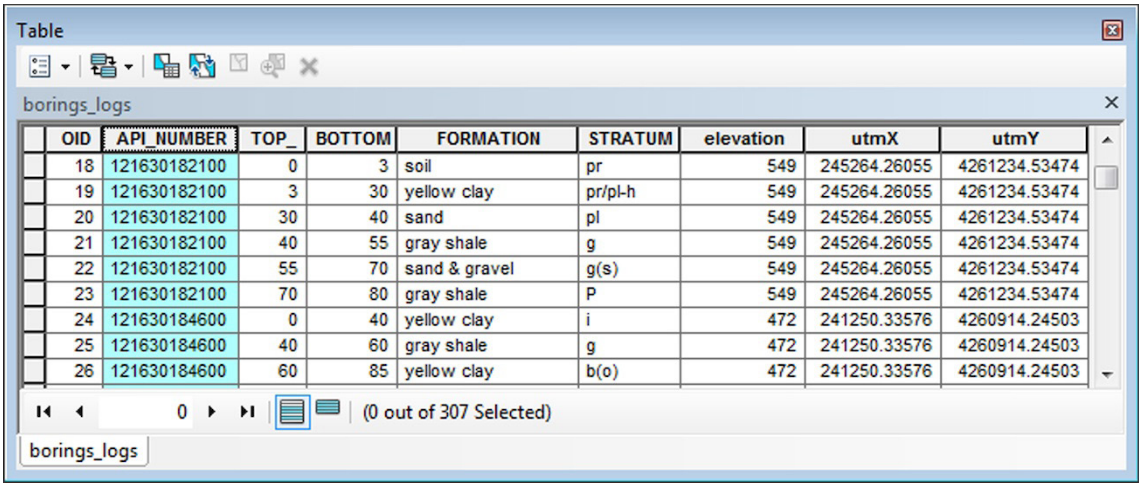


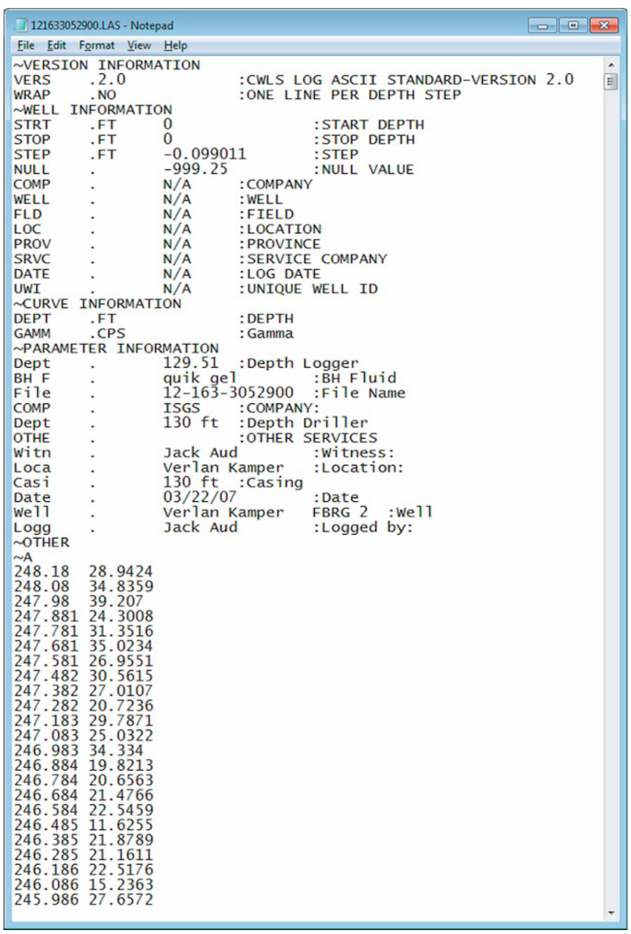
Table — borings_logs

OID	API_NUMBER	TOP_	BOTTOM	FORMATION	STRATUM	elevation	utmX	utmY
18	121630182100	0	3	soil	pr	549	245264.26055	4261234.53474
19	121630182100	3	30	yellow clay	pr/pl-h	549	245264.26055	4261234.53474
20	121630182100	30	40	sand	pl	549	245264.26055	4261234.53474
21	121630182100	40	55	gray shale	g	549	245264.26055	4261234.53474
22	121630182100	55	70	sand & gravel	g(s)	549	245264.26055	4261234.53474
23	121630182100	70	80	gray shale	P	549	245264.26055	4261234.53474
24	121630184600	0	40	yellow clay	i	472	241250.33576	4260914.24503
25	121630184600	40	60	gray shale	g	472	241250.33576	4260914.24503
26	121630184600	60	85	yellow clay	b(o)	472	241250.33576	4260914.24503

(0 out of 307 Selected)

borings_logs

Figure 8. An example of an input data table for creating 3D boreholes.



121633052900.LAS - Notepad

```
~VERSION INFORMATION
VERS    .2.0            :CWLS LOG ASCII STANDARD-VERSION 2.0
WRAP    .NO             :ONE LINE PER DEPTH STEP
~WELL INFORMATION
STRT    .FT     0               :START DEPTH
STOP    .FT     0               :STOP DEPTH
STEP    .FT     -0.099011       :STEP
NULL    .       -999.25         :NULL VALUE
COMP    .       N/A     :COMPANY
WELL    .       N/A     :WELL
FLD     .       N/A     :FIELD
LOC     .       N/A     :LOCATION
PROV    .       N/A     :PROVINCE
SRVC    .       N/A     :SERVICE COMPANY
DATE    .       N/A     :LOG DATE
UWI     .       N/A     :UNIQUE WELL ID
~CURVE INFORMATION
DEPT    .FT             :DEPTH
GAMM    .CPS            :Gamma
~PARAMETER INFORMATION
Dept    .       129.51  :Depth Logger
BH F    .       quik gel        :BH Fluid
File    .       12-163-3052900  :File Name
COMP    .       ISGS    :COMPANY:
Dept    .       130 ft  :Depth Driller
OTHE    .               :OTHER SERVICES
Witn    .       Jack Aud        :Witness:
Loca    .       Verlan Kamper   :Location:
Casi    .       130 ft  :Casing
Date    .       03/22/07        :Date
Well    .       Verlan Kamper   FBRG 2  :Well
Logg    .       Jack Aud        :Logged by:
~OTHER
~A
248.18  28.9424
248.08  34.8359
247.98  39.207
247.881 24.3008
247.781 31.3516
247.681 35.0234
247.581 26.9551
247.482 30.5615
247.382 27.0107
247.282 20.7236
247.183 29.7871
247.083 25.0322
246.983 34.334
246.884 19.8213
246.784 20.6563
246.684 21.4766
246.584 22.5459
246.485 11.6255
246.385 21.8789
246.285 21.1611
246.186 22.5176
246.086 15.2363
245.986 27.6572
```

Figure 9. An example of a LAS-formatted geophysical log file. The file is a basic text file with a "las" extension. Header information is ignored by the Borehole Tool. Each line of data represents a depth value and a geophysical measurement value.

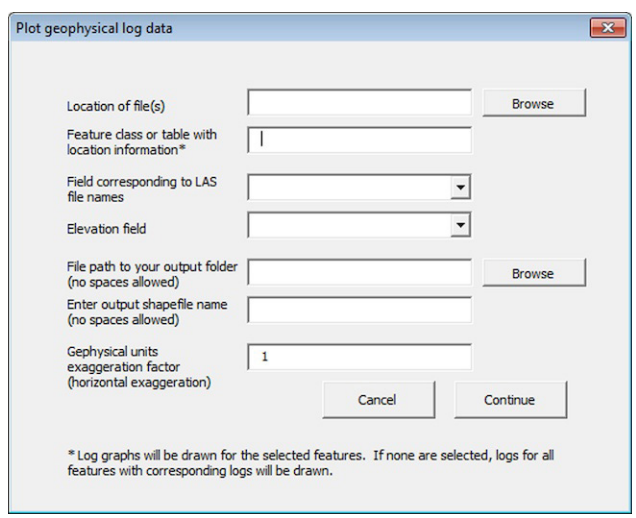


Figure 10. The input form for creating 3D geophysical log graphs.

Fence and Block Diagrams

It is possible to create 3D fence and block diagrams (fig. 11) from surfaces in ArcScene, though a fair amount of data processing is required if there are many surfaces in the geologic model. The workflow presented in table 1 (and in figure 12) could be automated using geoprocessing scripting with Python or using add-ins with ArcObjects.

Inputs:

- Raster top surfaces for each geologic unit, interpolated from point or contour data
- Depth rasters for each geological unit
- 2D vector lines representing lines of section

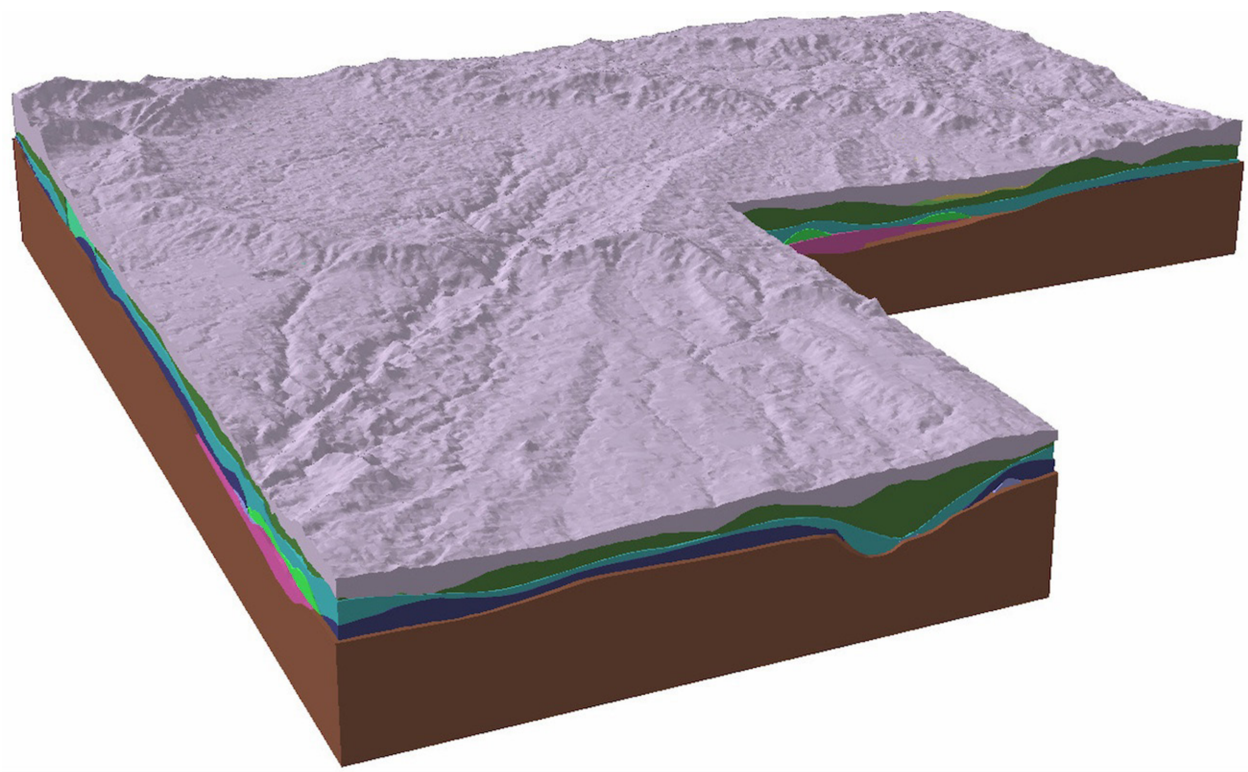


Figure 11. A geologic block diagram created in ArcScene.

Table 1. Process of creating a block diagram from surfaces in ArcScene.

	Process	Tool or Method	Input	Output
1	Subtract the depth raster from top surface raster to generate a bottom surface raster for each unit.	Spatial Analyst > Math > Minus	Raster surfaces for top elevation and thickness	Raster surface for bottom elevation
2	Convert each top and bottom surface raster into a TIN (triangulated irregular network) format.	3D Analyst Tools > Conversion > From Raster > Raster to TIN	Unit top and bottom elevation rasters	Unit top and bottom TINs
3	For fences, create narrow buffer polygons for the cross-section lines. For blocks, create a bounding area polygon.	Analysis Tools > Proximity > Buffer	2D cross section polyline	2D polygon buffer of line
4	Using the line buffers or bounding area polygon, extrude the top surfaces to the bottom surfaces. The output is a single multipatch feature for each extruded polygon. Repeat for each geologic unit.	3D Analyst Tools > Terrain and TIN Surface > Extrude Between	Unit top TIN, unit bottom TIN, 2D buffer polygons	3D multipatch features
5	Because the output multipatches contain no attribute data, populate the multipatch attribute tables with the geologic unit name or ID.	Add Field, Calculate Field	Multipatch features	Multipatch features
6	Merge all multipatches into one shapefile or feature class.	Data Management Tools > General > Merge	Separate shapefiles for each geologic unit	One shapefile containing all multipatches for all geologic units
7	To separate individual cross sections, query and export multipatches by cross section ID.	Select by Attribute, Data > Export	All cross sections combined in one multipatch shapefile	Separate shapefiles for each cross section

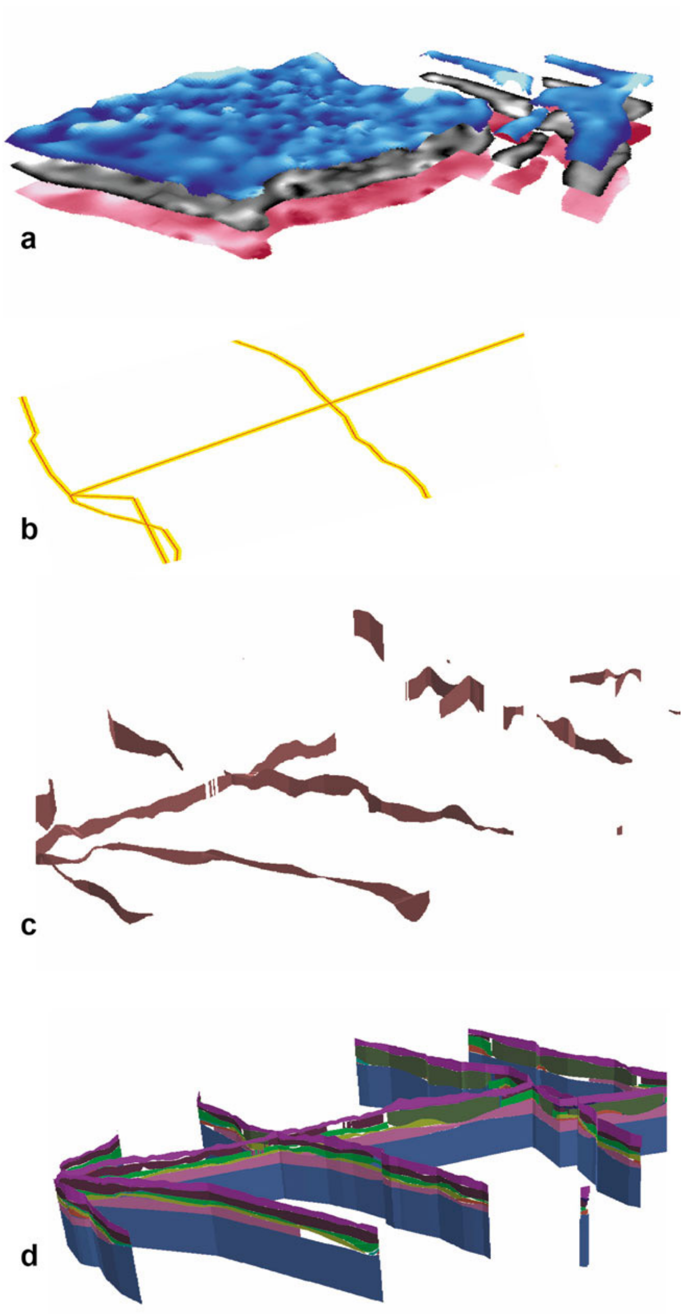


Figure 12. The process of creating multiple fences (or blocks) in ArcScene: (a) raster surfaces are created for units' tops and bottoms; (b) cross-section lines are buffered to create polygons; (c) the polygons are used as bounding areas to extrude multipatches between each unit's top and bottom surfaces; and (d) the extruded multipatches for each unit are merged.

Several other methods of buffering and extruding cross-section lines were tested, but only the method described here was found useful. Another method I tried was to extrude all top surfaces to a base height of 0. This produced multipatches with overlapping volumes when merged into a single layer. I then tried various 3D Analyst tools for 3D Features available in ArcGIS 10 (Intersect 3D, Difference 3D, Union 3D) in an attempt to remove the overlapping volumes. All of these methods proved to be too much for ArcScene to handle, either resulting in ArcScene crashing or producing errors citing lack of memory. It seems that the complicated multipatches created from TIN surfaces are simply too much data for the geoprocessor. Decreasing the resolution of the input surfaces or working with smaller areas of a model may produce more successful results with these 3D geoprocessing tools.

Acknowledgments

The geologic data shown in the screen shots represent the works of Illinois State Geological Survey geologists Steve Brown, Brandon Curry, Andrew Stumpf, and Drew Phillips.

Replacing the USGS Topographic Quadrangle: Basemap Alternative for Geologic Maps

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For decades, USGS topographic quadrangle maps have been used by geologists as the base for geologic mapping applications. USGS topographic maps have provided consistently high-quality map data and symbolization (fig. 1). A variety of derived products has been created from these topographic quadrangle maps, including greenline sheets, scans of the paper maps, Digital Raster Graphics (DRG), Digital Line Graphs (DLG), and Raster Feature Separates (RFS).

When the USGS ceased to update and revise the paper topographic maps, the currency of many geographic areas has gradually become unacceptable. For example, “Provisional Edition” USGS maps created with metric contours have not been updated to be consistent with the standard contours in feet. DLG feature layers were never completed for many states, first generation DRGs are too coarse in resolution, second generation DRGs were never completed nationwide,

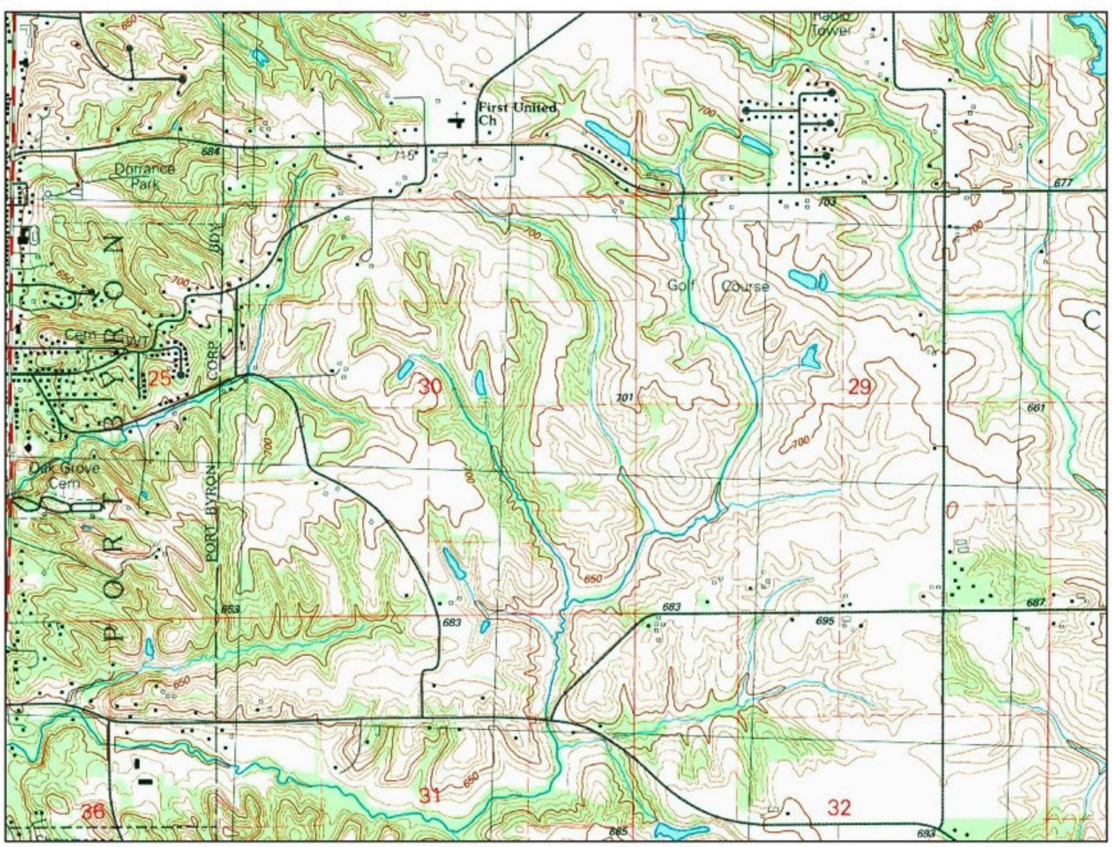

Figure 1. USGS 7.5-minute Port Byron, IL-IA, quadrangle, published in 1991.

and RFS products are no longer produced by the USGS. Many states have been left with incomplete digital base data and quadrangle maps that are significantly out of date.

US Topo

For the past 125 years, the USGS has produced topographic quadrangle maps that have served as the base for geologic mapping applications. In 2009, the USGS introduced the replacement for the lithographic printed 1:24,000-scale topographic map—the US Topo (see fig. 2). US Topo maps have a much different appearance and generally have less feature information than traditional USGS topographic quadrangle maps. US Topo data layers include contours, roads, geographic names, hydrographic features, and an imagery base; additional layers eventually will be added including expanded transportation, boundaries, structures, and land cover feature information. As of April 2012, nearly 55,000 US Topo maps for all or portions of 39 states were available at the USGS Map Store (*http://store.usgs.gov/*).

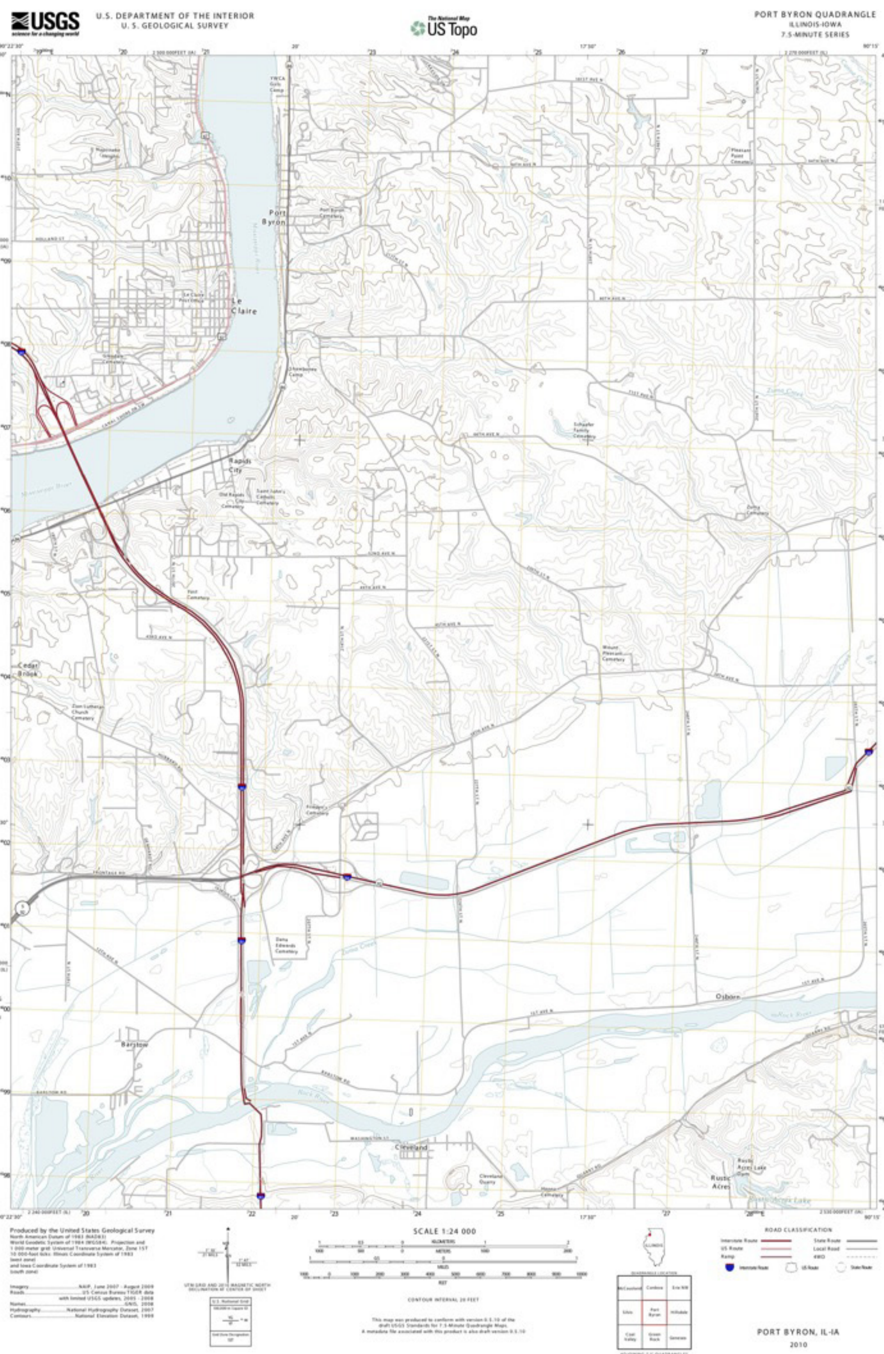

Figure 2. US Topo version of Port Byron quadrangle, published in 2010.

US Topo maps are only available in GeoPDF format. They include data layers similar to the USGS topographic map, including an imagery base (not shown in figure 2). For those areas for which US Topo coverage is available, there are challenges in using the maps as base information for geologic mapping (fig. 3). For example, it is currently not possible to import a GeoPDF-format file into ArcGIS software; it is also not possible to import the feature data into design software such as Illustrator and retain the critical georeferencing information or maintain the feature data as separated layers. Furthermore, whereas the roads, geographic names, and hydrographic features have been updated, the contour data layer for the majority of the US Topo maps has not been updated, and the appearance of the contours has changed significantly. Finally, as more high-resolution LiDAR (Light Detection And Ranging) topography becomes available, geologists will be faced with the problem that geology mapped using LiDAR will not register to USGS base data.

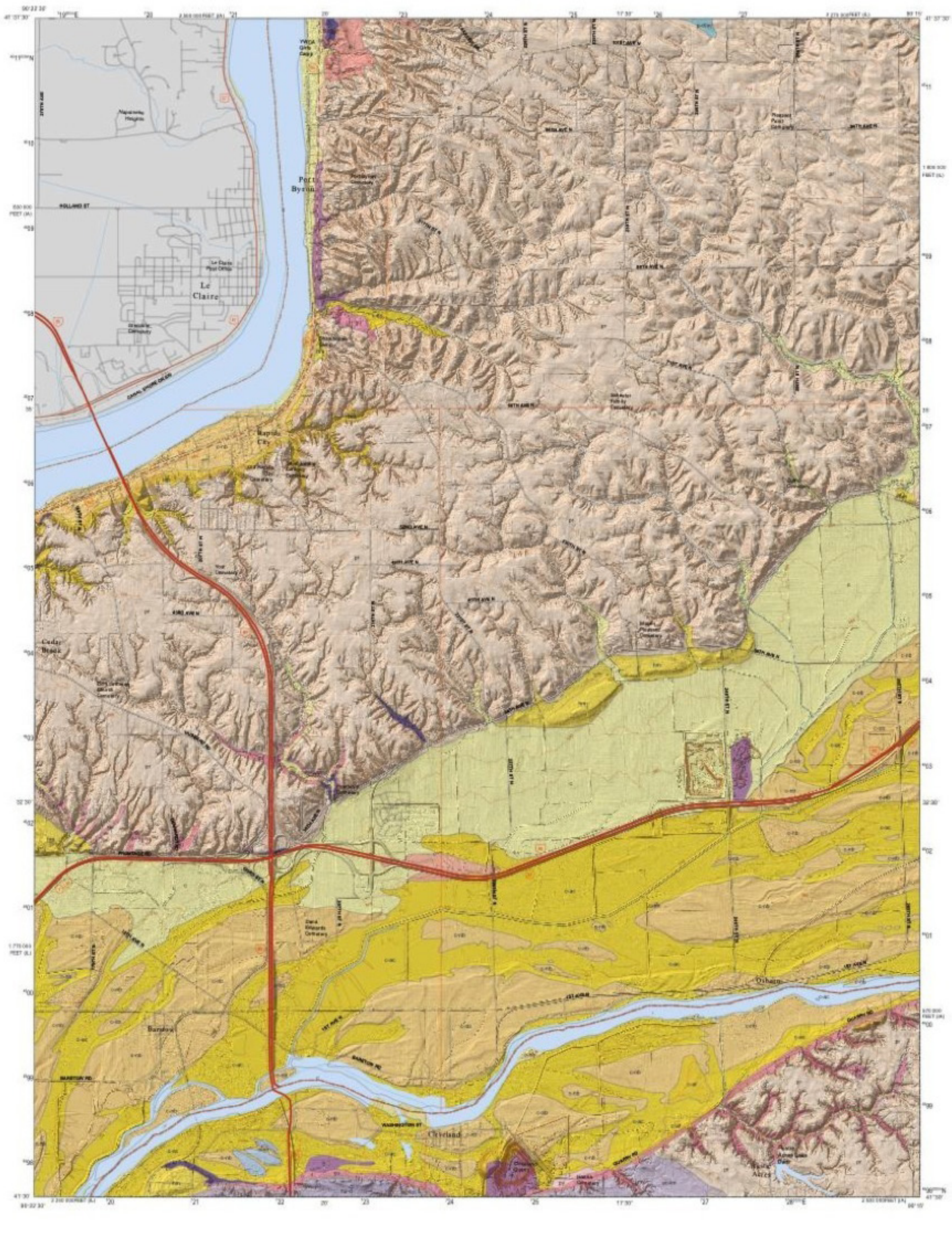

Figure 3. US Topo version of Port Byron quadrangle, with surficial geology.

Because topographic information is a critical input to geologic mapping, it is important to understand the changes to the contour feature data represented on the US Topo maps as compared to the traditional USGS 7.5-minute topographic quadrangle maps. The accuracy and content of the topographic information on US Topo maps is dependent upon the quality of the elevation data within the USGS National Elevation Dataset (NED), which is variable across the United States both in terms of spatial and temporal resolutions. US Topo and NED data are available at *http://nationalmap.gov*. A mixture of mostly one-third arc-second (nominal post spacing (NPS) of 10 meters) digital elevation model (DEM) data and lesser amounts of one arc-second (NPS of 30 meters) DEM data represent the NED source information for the US Topo contours. At this date, LiDAR-enhanced elevation data are completed for approximately one-quarter of the United States, and the majority of one-ninth arc-second (NPS of 3 meters) NED data are produced from LiDAR source information. For those areas where LiDAR data have been ingested into the NED, the original resolution elevation data are first downsampled to one-third arc-second resolution for production of US Topo contours. LiDAR-derived elevation data provide far more current, accurate, and detailed topographic information than has been used for the historical 7.5-minute topographic quadrangles, which are the dominant source for the NED. LiDAR data give us the opportunity to evaluate NED data against a topographic model that is significantly more accurate. This is especially true for geomorphically active areas where the NED source data are several decades old.

The USGS 7.5-minute Port Byron, IL-IA topographic quadrangle was selected for the evaluation (fig. 2). The US Topo for this quadrangle was produced in 2010, and the most recent historical edition was published in 1991 (fig. 1). The contour feature layer for the 1991 edition was produced from photogrammetric compilation of 1986 aerial photography, and a 1:24,000-scale hypsography DLG was created from scanning and conversion of the contour mylar feature separate for the quadrangle. Figure 4 shows the DLG hypsography for a portion of the quadrangle on a shaded relief image produced from NED one arc-second DEM data, which as of this date is still the best available NED source data for the quadrangle.

Figure 5 shows cartographic contours produced from source 2009 LiDAR DEM data with a nominal post spacing of 1.2 meters. The DEM data were resampled to one arc-second resolution to match the NED source data and used to create the shaded relief base image. The original photogrammetric-based contours in figure 4 compare favorably to the contours generated from the resampled LiDAR DEM. Despite the significant downsampling of the original LiDAR DEM, note the enhanced landscape feature detail that is retained as compared to the NED source one arc-second DEM shown in figure 4.

Figure 4. USGS Hypsography Digital Line Graph for a portion of the Port Byron IL-IA quadrangle.

Figure 5. Cartographic contours produced from LiDAR source data for a portion of the Port Byron IL-IA quadrangle.

Figure 6 shows the contour feature layer for the 2010 Port Byron, IL-IA US Topo map, produced by direct generation from the NED one-third arc-second DEM data. The process of interpolating a DEM from contour data and then extracting contours from that DEM necessarily degrades the accuracy and detail of the original contour data. When the US Topo contours are compared to the original source contours (fig. 4) from which the NED was generated, it can be seen that important landscape feature details have been lost. This is more easily seen in figure 7, where the US Topo derived contours and the hypsography DLG-based contours have been superimposed for comparison. Note how finger-tip tributaries are missing, and slope facets are smoothed, resulting in a geometrically smoothed landscape surface. The discrimination of topographic features critical to the interpretation of geologic features has been substantially reduced.

Figure 6. US Topo contour feature layer for a portion of the Port Byron IL-IA quadrangle; contours produced from NED one-third arc-second DEM data.

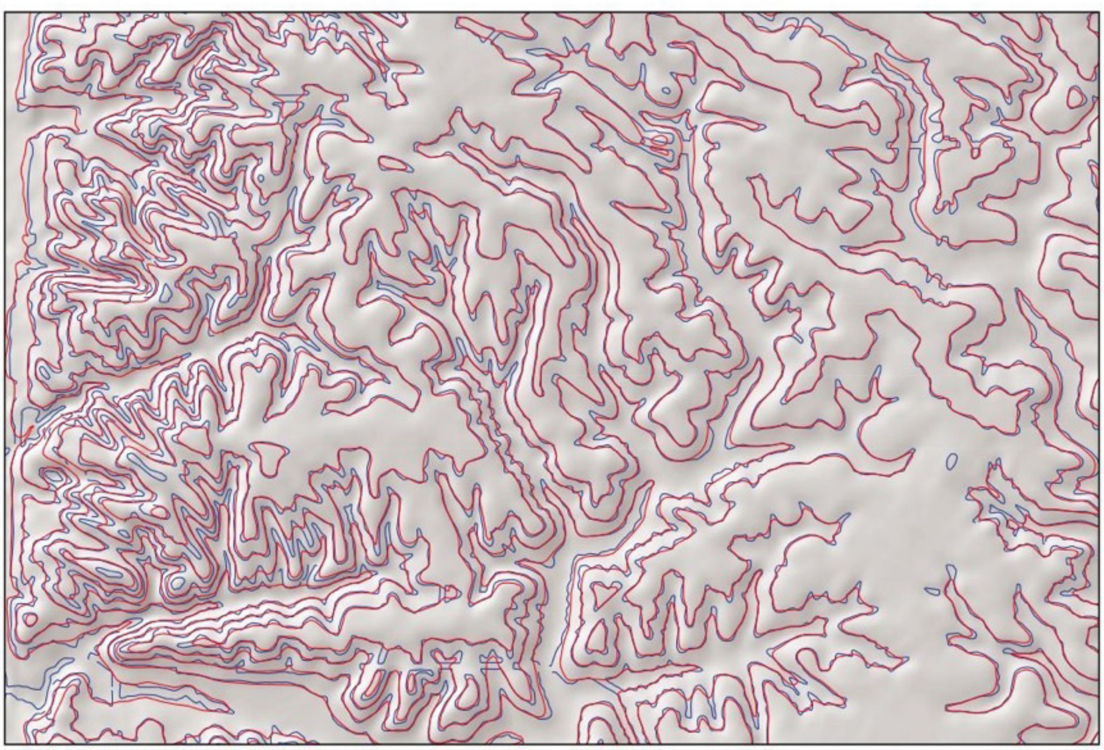

Figure 7. Comparison of contour feature layer from US Topo and Hypsography DLG for a portion of the Port Byron IL-IA quadrangle.

Basemap Alternative

Because of the lack of availability and the outdated status of USGS topographic quadrangle base data products, coupled with data format and quality issues with the US Topo, it makes sense to build custom basemaps for new geologic products. TIGER-based transportation and NHD hydrographic data, LiDAR-produced contours and shaded relief images, and, when available, a USGS scanned lettering feature layer from the original USGS topographic quadrangle maps can be integrated to produce a current and high-quality basemap for geologic mapping applications (fig. 8).

Note: Discussions with USGS and additional investigation since this poster was presented in May 2011 have shown that significantly improved results are possible when NED one-third arc-second source data are used to generate the contour feature layer for the US Topo maps. It is expected that by the end of 2013, all one arc-second elevation source data remaining in the NED will be replaced by one-third arc-second or better source data. New versions of US Topo maps for Illinois will be available in June 2012.

Figure 8. Custom basemap for Port Byron quadrangle; includes 2009 TIGER, LiDAR, and NHD data.

Inventory Mapping and Characterization of Landslides Using LiDAR: Kenton and Campbell Counties, Kentucky

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Introduction

Landslide identification and hazard mapping using light detection and ranging (LiDAR) have proven successful in Kentucky and other landslide prone areas of the United States, such as Oregon, Washington, and North Carolina (Burns and Madin, 2009; McKenna and others, 2008; Wooten and others, 2007) . The purpose of this project was to develop a methodology for using LiDAR data to document preexisting landslides in Kenton and Campbell Counties, Kentucky (fig. 1). To do this, potential landslides were mapped and digitized that previously were not visible on existing maps or coarse digital elevation models (DEMs). Field verification of these mapped locations, where possible, also was conducted. Using high-resolution LiDAR to identify potential landslides provides a framework for analyzing landslide data that are crucial to understanding landslide susceptibility and reducing long-term losses.

Impact

Landslides have long been a problem in northern Kentucky. Steep topography, bedrock geology, and unconsolidated soils make many parts of northern Kentucky susceptible to landslides (Agnello, 2009; Potter, 2007). A 324-square-mile (mi^2) area in Kenton and Campbell Counties consists of a heavily populated northern part close to Cincinnati and a more rural southern part (fig. 2). Many documented landslides have damaged roads, homes, and other infrastructure, thereby causing financial losses for property owners and making decisions difficult for government agencies and developers. Data obtained from the Kentucky Transportation Cabinet show that, from 2002 to 2010, landslide repair costs to roads exceeded $1.5 million in these counties (Overfield, 2014). From 2003 to 2013, the Kentucky State Emergency Management Office spent approximately $5.3 million on acquisition of landslide-damaged homes (Esther White, University of Kentucky Hazard Mitigation Grant Program, written communication, 2011). In addition to direct costs, indirect costs such as commerce hindered by road closures, devalued property, and environmental effects may exceed direct costs. The slow nature of movement in some landslides, however, many of which are not related to roads, leads to incremental damage that can span several decades, often making people less aware of the problem. Many landslides go unreported and citizens do not take advantage of resources to become educated about how to recognize and mitigate the problems. This project will identify landslides not previously documented, provide insight into the distribution of landslides, and indicate areas of potential concern for future slope failure.

Methodology

The following steps were taken to identify landslides:

- Applied Imagery's Quick Terrain Modeler software (*http://appliedimagery.com/*) was used to create DEM data sets from LiDAR LASer (LAS) files. LAS files are an industry standard binary file format capable of storing more information.
- DEMs were imported into Esri's ArcMap for visualization, spatial analysis, and digitization.
- Digitized landslides were reexamined in 3D in Quick Terrain Modeler (v. 7.1.0).
- Locations were field checked.

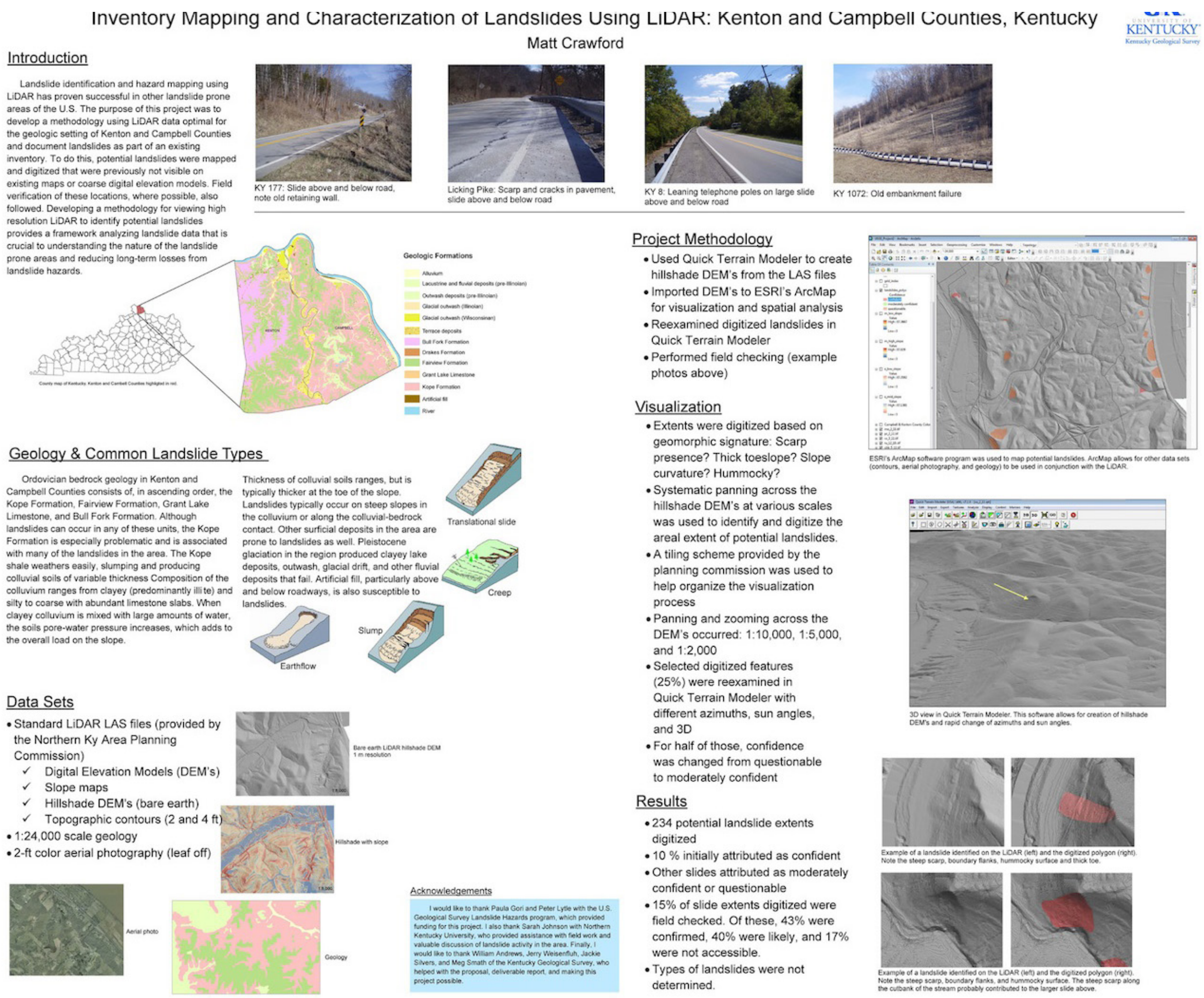

Figure 1. Page-size version of DMT'11 poster; see full-resolution image at *http://ngmdb.usgs.gov/Info/dmt/DMT11presentations.html*.

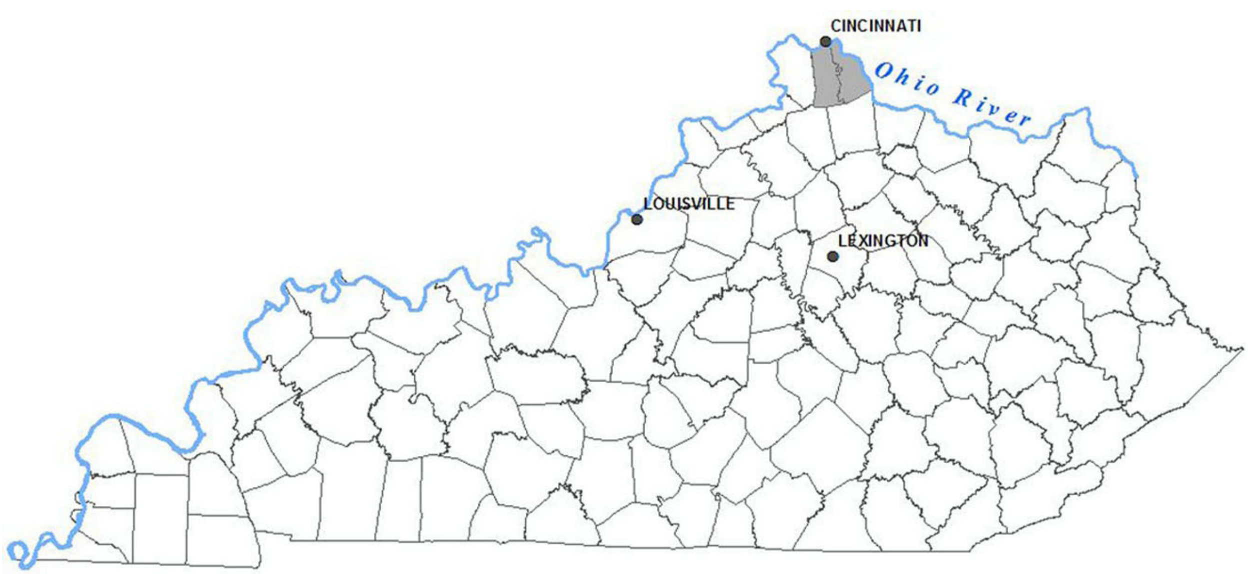

Figure 2. State of Kentucky showing (in gray) the location of Kenton and Campbell Counties (Kenton is to the west, Campbell to the east).

Data Sets

Standard LAS files from LiDAR were processed to create DEMs, slope maps, and hillshade DEMs. LAS files are binary files that contain the x, y, z data as well as the classifications of the multiple point returns (ground, trees, buildings, vehicles, power lines, and bridges). The ground classification points were used to create bare-earth, hillshade maps and were the primary data set used for visualization and landslide mapping. The horizontal resolution of the data was one meter. The LAS files were imported into Quick Terrain Modeler to create the hillshade, bare-earth DEMs. Hillshade DEMs of various extents were created, with a sun angle of 45° and an azimuth of 35° specified. The models were exported as hillshade DEMs (geo-referenced TIF files) that could be used in a geographic information system (GIS) with other spatial data sets. Other data sets used were topographic contours (2- and 4-foot (ft) intervals), 2-ft-resolution color aerial photography, and 1:24,000-scale geologic map data. The aerial photography was taken during a season without leaves on trees (referred to as "leaf-off"), allowing better views of the ground and structures.

Visualization and Analysis

Potential preexisting, previously undetected landslides were identified by visual examination of slope morphology at different scales. The bare-earth hillshade DEMs were used in ArcMap to map potential landslides (fig. 3). ArcMap allows for other data sets (contours, aerial photography, geology, and others) to be used in conjunction with the LiDAR. The hillshade DEMs were systematically panned at various scales to identify and digitize the areal extent of potential landslides. Draping the topographic contours over the hillshade was important for accentuating the slope geomorphology. A reference grid was used to help organize the panning and zooming across the DEMs. Examination was done at 1:10,000, 1:5,000, and 1:2,000 scales. All digitizing of potential landslide extents was done at a scale of 1:2,000. Potential landslides were primarily identified and mapped on the basis of geomorphic expression on the hillshade models. Steep scarps, hummocky terrain, concave and convex areas, and thick toeslopes were possible indicators of landslides. Changes in contour spacing helped accentuate thick toeslopes where the landslide deposits

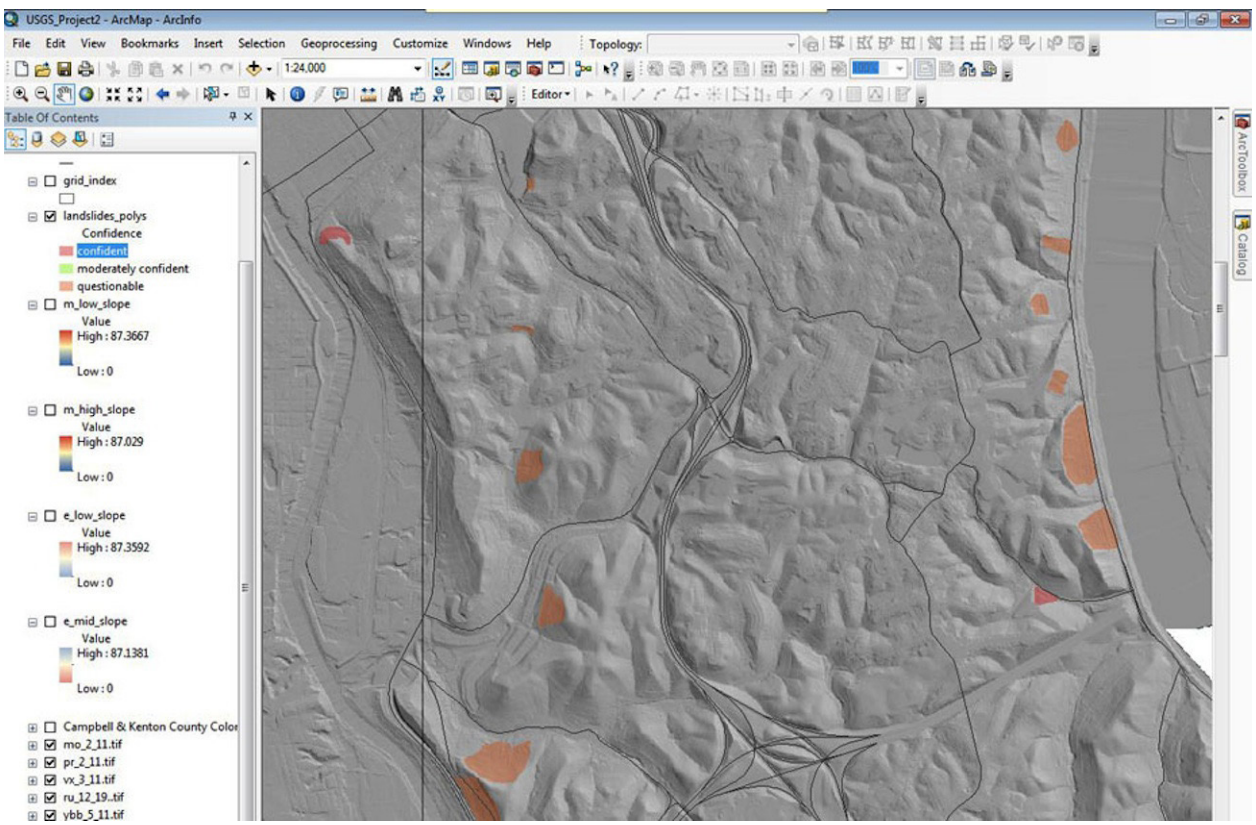

Figure 3. ArcMap project showing a bare-earth LiDAR hillshade DEM and mapped landslides.

had spread out, creating a gentler slope. The geology and leaf-off aerial photography also were used in the visualization and analysis processes. Evidence of landslides, such as repaired roads and leaning trees, occasionally was seen in the aerial imagery.

Potential landslide extents were digitized and assigned general confidence levels. Confidence levels assigned to digitized polygons were "confident," "moderately confident," and "questionable," based on the visual clarity and geomorphic signature on the LiDAR hillshade model. Some of the questions dictating the confidence level included: How visible is the scarp? How visible is the toeslope? How much concavity or convexity is shown? Is the hummocky terrain actually a landslide or is it an otherwise modified surface that was forested? A standard rating system was not used to classify confidence; instead, it was a subjective decision made by the mapper.

Distinguishing between hummocky landslides and a general "roughness" in the LiDAR hillshade was a challenge. ["Roughness" refers to the hillshade quality and local landscape variability. The roughness may represent actual landscape ruggedness and discrete features, or a "false topography" because of sun angle, azimuth, resolution, and bare-earth derivation of actual landscape.] The data-processing algorithms that produce bare-earth hillshade models also can create false ground-surface roughness (McKenna and others, 2008). Roughness appears to be more prominent on forested slopes, particularly slopes with many cedar trees. Southwest-facing slopes also exhibited more roughness than slopes facing other directions and of similar land use. This would most likely change if hillshade DEMs were created with different azimuths. Mapping landslides in the more urban areas of Kenton and Campbell Counties also was a challenge. Densely populated neighborhoods with altered landscapes and abundant fill areas can be deceiving in a bare-earth surface model. Many of these areas appear to have landslides, but typically are artificially contoured terrain rather than a landslide. The color, leaf-off, 2-ft-resolution aerial photography helped clarify questionable geomorphology in urban areas.

Knowing where the geologic contacts between formations are located also helped in the analysis of slope geomorphology. Many places initially thought to be a landslide scarp or to have questionable geomorphology were actually the contact between the Fairview Formation and the underlying Kope Formation. The Fairview is interbedded limestone and shale with about 40 percent limestone near the base increasing to about 65 percent near the top. The Kope consists of approximately 80 percent shale with minor interbedded limestone. It is 200 to 250 feet thick, primarily cropping out along the lower parts of hills. . The transition from a more resistant limestone to weaker shale shows up very well in the LiDAR hillshade. The breaks in slope in the Fairview are probably limestone beds that extend in a more continuous fashion along the slope than would a landslide scarp.

Reexamination of Surface Models

After initial identification of potential landslides in ArcMap, selected digitized features were reexamined in Quick Terrain Modeler for verification. This software allows for the rapid change of azimuths and sun angles (fig. 4). Different lighting and perspective on slope geomorphology and potential landslides help with assigning the confidence level. Scarps or concavity observed with one sun angle may appear completely different with other lighting orientations. In addition, Quick Terrain Modeler allows for 3D visualization, whereas ArcMap is best for 2D map view of data sets. Using rapid zooming and panning tools with 3D was very helpful in assigning confidence to the digitized landslide extents, confirming well-defined scarps, flanks, or thick toeslopes. Approximately 25 percent of the slides (about 50) identified using ArcMap were viewed in 3D with various lighting orientations. For about half of those, the confidence was changed from questionable to moderately confident, and the other half remained as questionable. Potential landslides that initially were attributed as questionable and not viewed in 3D were left as questionable.

Field Checking

Field checking was attempted for approximately 20 percent of the landslides whose extents were digitized. A strict project timeframe and inaccessibility controlled how much field verification was possible. Clusters of landslides were visited in an attempt to verify as many as possible. Separate attributes were assigned to the field-checked landslides: "confirmed"—landslide deposits and geomorphic features were observed in the field; "likely"—the actual deposit was not observed, but a landslide is likely based on proximity to other slides or other telling geomorphic features; "observed but could not determine"—the deposit was accessible but further field investigation was required; and "no access"—the landslide was on private property, on inaccessible terrain, or could not be seen.

Many of the confirmed landslides could be seen from the road, and road damage typically was associated with them (fig. 5). Recent scarps also were present in many slides, and deposition was active toward the toe of the slide. Determining the location of potential landslides was a subjective process. For example, a potential landslide might have been identified on a slope, and slumping in the road below it provided field verification, but it was not clear whether there was active sliding above the road or if there was geologic control on the geomorphology of the slope. Many of these slopes are creeping, but distinguishing between active creep and relict, non-active movement makes attribution difficult.

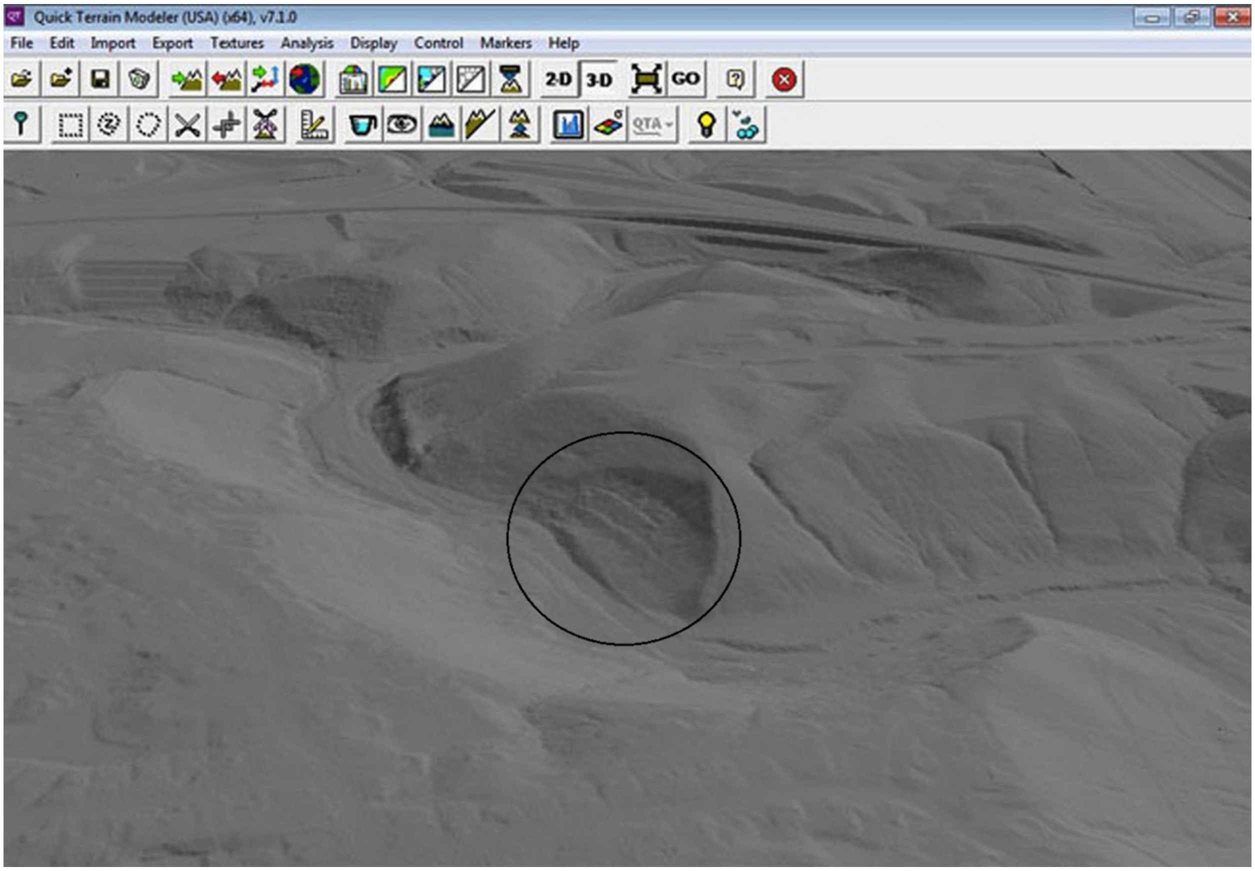

Figure 4. Rotated 3D view of LiDAR hillshade in Quick Terrain Modeler that accentuates the geomorphology when azimuth and sun angle are changed. Landslide is circled.

Figure 5. Photograph of landslide area along KY 8. Note leaning telephone pole.

Results

Two hundred thirty-four potential landslides were detected in Kenton and Campbell Counties, and their extents were digitized. Twenty landslides (approximately 9 percent) were initially attributed as confident (fig. 6). The other slides were attributed as questionable or moderately confident (fig. 7). The LiDAR hillshade geomorphology, geology, and proximity to urbanized areas dictated the initial classification. Reexamination in Quick Terrain Modeler changed the initial classification (that is, from questionable to confident, or vice versa) of some of the slides. Landslides were not deleted from or added to the inventory after Quick Terrain Modeler was used. Forty-five landslides (approximately 20 percent) were field-checked. Of those, 20 were confirmed, 18 were likely or observed but could not be determined, and 7 were not accessible. Landslide type (translational or rotational) was not determined by LiDAR visualization. If landslide type could be determined in the field, then it was noted. Many of the landslides mapped are not associated with roadways and are in rural, wooded areas that are on private property. Using airborne LiDAR for detailed inventory mapping significantly improves awareness of landslide locations not previously known, especially in forested and suburban landscapes.

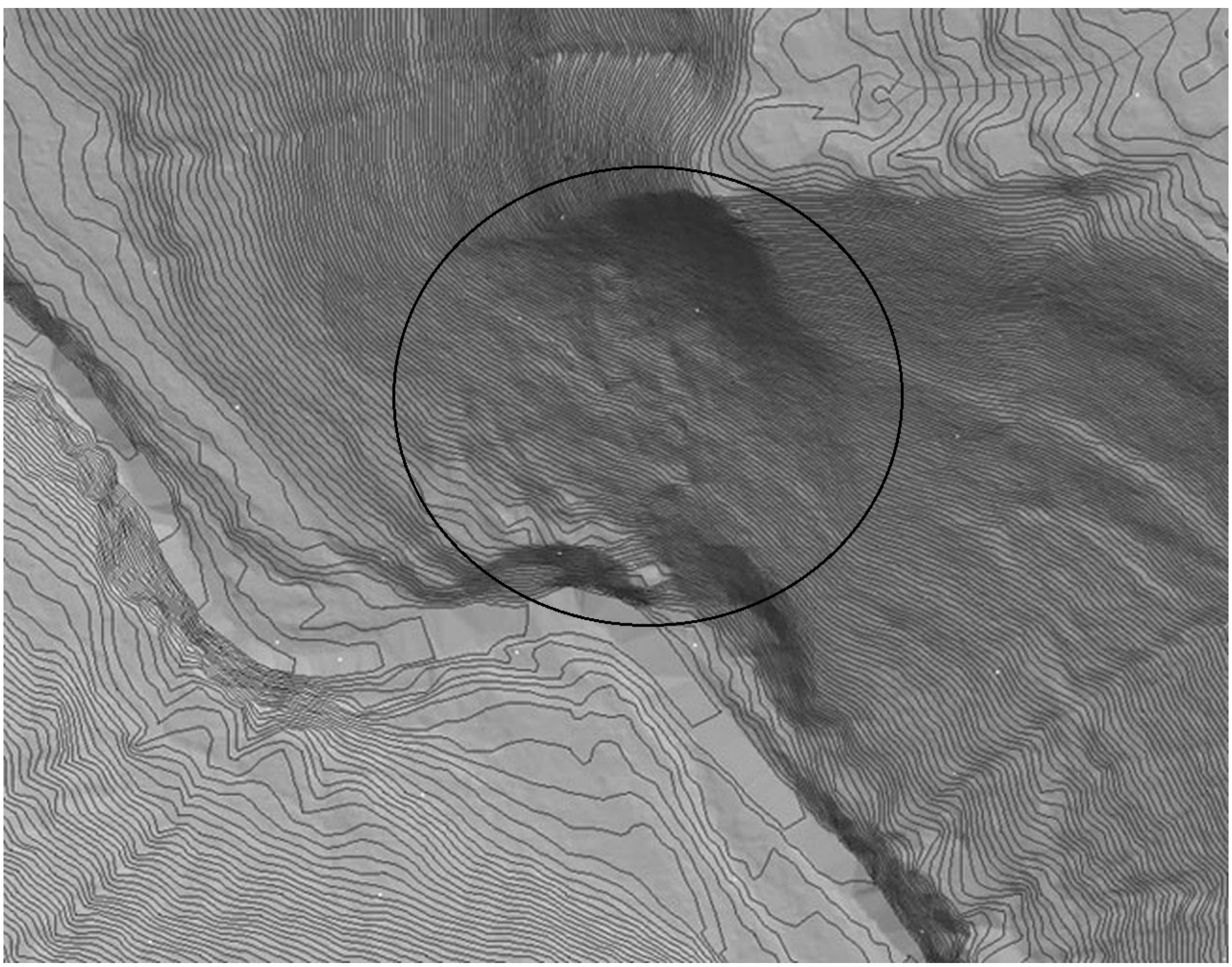

Figure 6. Mapped landslide on LiDAR hillshade draped with topographic contours (2 ft). Slide occurs at cutbank in a stream at the toe and is approximately 455 ft long down the axis of the slide. Note hummocky surface of slide area, slide flanks, and steep scarp area near the top of the slope.

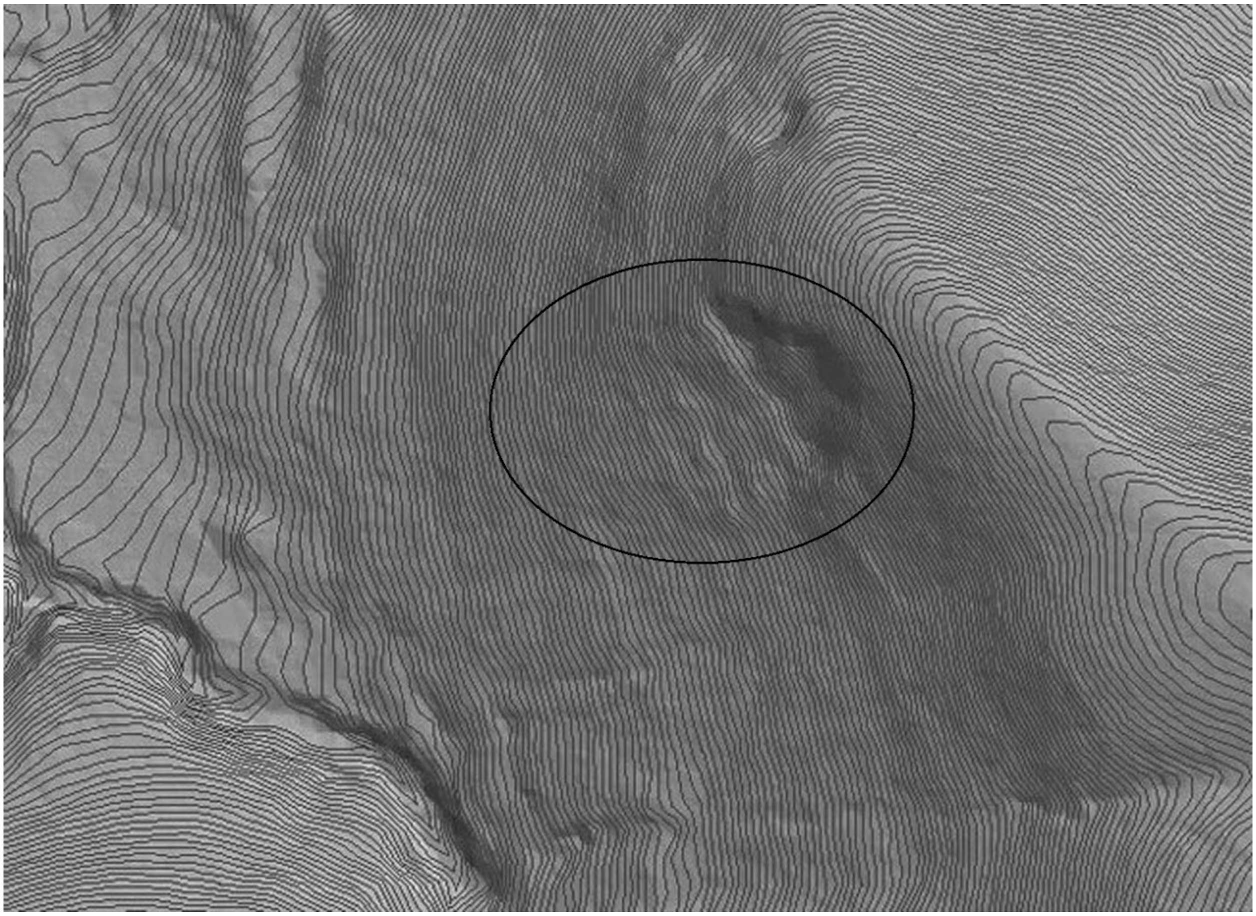

Figure 7. Mapped landslide on LiDAR hillshade draped with topographic contours (2 ft). Slide occurs mid-slope and is approximately 280 ft long down the axis of the slide. Note hummocky surface of slide area and steep scarp. This slide occurs in a wooded area that otherwise would not have been recognized.

Conclusion

This study successfully used LiDAR to map landslides in Kenton and Campbell Counties. The landslides were added to an existing inventory database, approximately doubling the number of documented landslides for the area. Although there were some limitations, the methodology provided here can be a precedent for future studies. Potential landslides were identified that would not have been identified with traditional, lower-resolution GIS data. This method documents landslides for which researchers have not had the resources to identify in the field, thereby saving time and funding. One of the strengths of using LiDAR is being able to map potential landslides in areas not accessible by roads. Much of the landslide data in the existing Kentucky Geological Survey (KGS) landslide inventory is from road-related slide activity, and these landslides are too small to detect using LiDAR or were repaired before the LiDAR was flown. Mapping landslide locations on slopes unrelated to roads or other human activity can provide a better understanding of landslide activity within a natural geologic and geomorphic context.

In addition to revealing inaccessible and small slides, this methodology can indicate future failures. Many of the landslides mapped are old, creeping slides that may not yet have become a problem. A heavy rain or other trigger could cause these existing landslides to move again, potentially quickly and unexpectedly. Hazard mitigation efforts continue across the State to help citizens facing landslide problems. Although mitigation projects provide solutions, obtaining funding is often difficult, and the process can take years to implement.

This study was limited by time and ability to field-check identified landslides. Urbanization in parts of Kenton and Campbell Counties also made it challenging to identify landslides using LiDAR. Extensive neighborhoods, large industrial areas, and Interstate highways can mask the natural slope geomorphology. The use of Quick Terrain Modeler helped with setting the initial confidence level for landslide identification. Using software specifically designed for processing large amounts of LiDAR data and having the capability to view the data in 3D is very effective. Although ArcMap was effective for 2D mapping, many traditional GIS programs cannot process large data sets with the speed needed for detailed slope visualization.

The amount of LiDAR data available for Kentucky will increase in the future. High-resolution data sets will become available for other landslide prone counties, and studies similar to this one can provide precedent for future landslide inventory mapping. An automated program that completes the image analysis part of landslide mapping would be very beneficial. Future mapping will greatly enhance the existing KGS landslide inventory, which is a foundation for effective hazard and risk analysis.

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Using High-Resolution Digital Terrain Models to Improve Bedrock and Surficial Geologic Mapping in Virginia

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Abstract

Shaded relief maps generated from elevation control data associated with high-resolution orthoimagery have been used to improve 1:24,000-scale geologic mapping in Virginia. These shaded relief maps have been demonstrated to be useful in delineating geologic, geomorphic, and geologic hazard features, especially in highly vegetated areas. Features such as terraces, sinkholes, fault scarps and landslide deposits are often difficult to detect on the ground, on topographic maps or on aerial photos, and may only be visible on shaded relief maps derived from high-resolution digital terrain models (DTMs).

In the Elkton West 7.5-minute quadrangle, located in the Valley and Ridge Province near the southern end of Massanutten Mountain, areas underlain by residuum, mountain slope colluvium, and older debris-flow deposits are not evident on a standard 1:24,000-scale topographic map with a 40-foot (ft) contour interval. These geologic map units can, however, be identified on the shaded relief map due to subtle differences in slope pattern and dissection. The map also allows for accurate delineation of modern flood-plain and terrace deposits along the South Fork of the Shenandoah River. In the Providence Forge 7.5-minute quadrangle, located in the Coastal Plain Province east of Richmond, the shaded relief map enables correlation of Pleistocene terraces and underlying marine and nearshore facies of older stratigraphic units, previously difficult to resolve. Scarp and terrace morphology, which generally follows consistent elevations, can be further refined by extending the use of shaded relief maps across the Coastal Plain. Other features such as fault lineaments and the extents of mined-out areas in pits and quarries also are revealed using the shaded relief maps.

Many States now use bare-earth light detection and ranging (LiDAR) elevation data, but, at present, Virginia lacks comprehensive LiDAR coverage. However, the DTMs generated from high-resolution orthoimagery have proven to be a useful alternative in delineating geologic features when LiDAR data are unavailable, and the DTMs are substantially more useful than standard 7.5-minute topographic maps.

Methodology

The Virginia Base Mapping Program (VBMP) was initiated in 2001 to develop orthoimagery for the entire Commonwealth of Virginia. The purpose of this program was to create a consistent, accurate base map that all State, local, and Federal government agencies could use for spatial data applications. As a part of the VBMP, the Sanborn Map Company, under contract to the Virginia Geographic Information Network (VGIN), a part of the Virginia Information Technology Agency (VITA), also developed DTMs primarily for the purpose of orthorectification of imagery. This product was made available in addition to the source imagery for the purposes of planning and hydrographic analysis.

In the VBMP DTM data, the terrain is represented by masspoints and breaklines. For areas mapped to 1 inch = 200 ft, the aerial imagery was collected at a 1:14,400 scale at a flying height of 7,200 ft above the mean terrain. For areas mapped to 1 inch = 100 ft mapping standards, the aerial imagery was collected at 1:7,200 scale at a flying height of 3,600 ft above the mean terrain. Ground control is used to support the orthophoto mapping by either placing air target panels on existing permanent monuments or photographic identification of strategic points. The coordinates were collected via ground survey techniques. Aerial triangulation was performed on softcopy workstations using high-accuracy stereo plotters and software with a fully analytical triangulation adjustment. The data were photogrammetrically stereo-compiled to North American Datum 1983; Virginia State Plane North or South Zone, as applicable (VGIN, 2007). All DTMs were developed from the imagery acquired in 2006 or 2007, using high-accuracy stereo plotters and traditional manual photogrammetric techniques for generating the breaklines and masspoints.

Division of Geology and Mineral Resources (DGMR) staff use VBMP DTM data (masspoints and breaklines) delivered in Microstation CAD .DGN format to create Triangulated Irregular Networks (TINs) in ArcGIS's 3D Analyst for the purpose of representing surface morphology. The Elkton West 7.5-minute quadrangle was chosen as a test case to see if the data could prove useful for surficial mapping projects (fig. 1). A raster hillshade of the Elkton West quadrangle was generated in ArcGIS's Spatial Analyst. After it was determined that this product was useful for mapping purposes, raster hillshades were generated for other quadrangles.

Geomorphic Features From Surficial Mapping in Elkton West 7.5-Minute Quadrangle

The surficial geologic map of the Elkton West 7.5-minute quadrangle was mapped by Matt Heller and Scott Eaton in 2008 for the STATEMAP cooperative mapping program (Heller and Eaton, 2010). They relied on a variety of sources and methods, including field work, topographic maps, soils maps, and aerial photography. A preliminary map was produced that showed the general distribution of the surficial deposits in the quadrangle. This map was extensively revised and improved when the raster hillshade for the quadrangle became available. The boundaries of surficial deposits, such as alluvial fans, debris flows, and ancient terrace surfaces, were refined with the higher-resolution provided by the DTM hillshade (fig. 2). Heller and Eaton (2010) also were able to better subdivide terrace and debris-flow deposits by relative age (fig. 3). In addition, smaller and subtle surficial deposits were identified and included on the map.

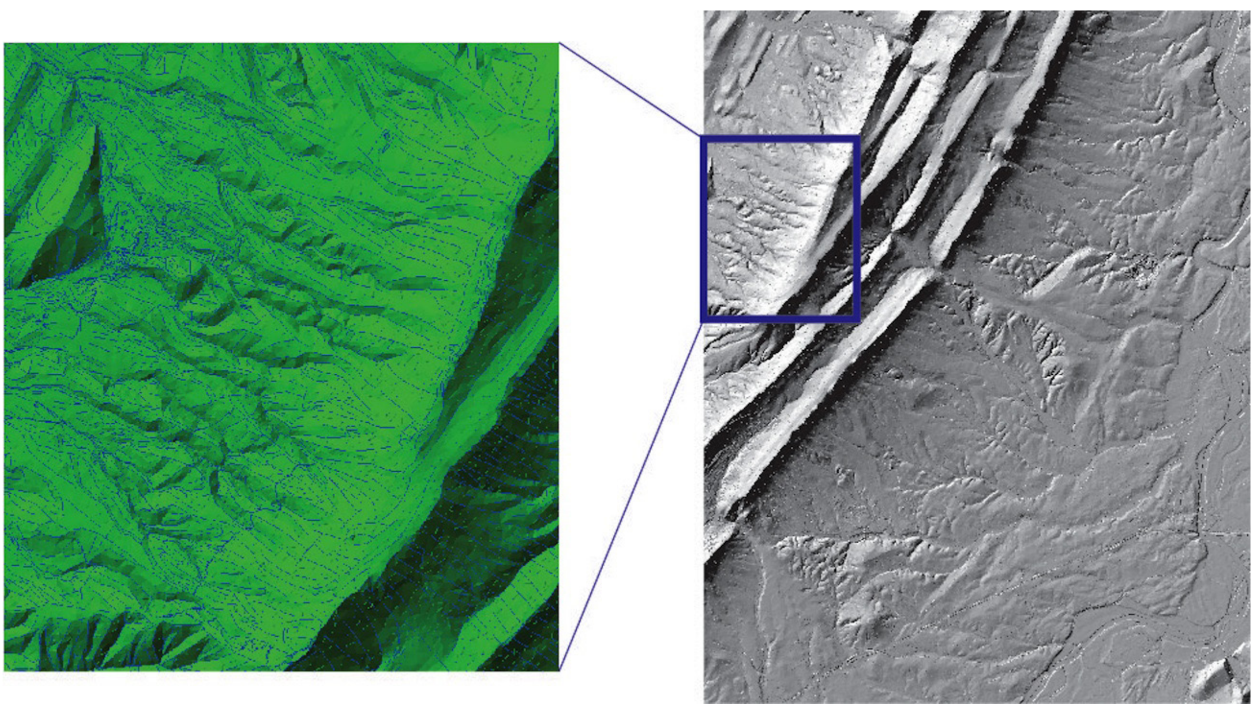

Figure 1. A TIN for a portion of the Elkton West 7.5-minute quadrangle generated from masspoints and breaklines is shown on the left. The blue dots represent masspoints, which are regularly spaced. The blue lines are breaklines, representing ridges, valley bottoms, and some types of infrastructure, such as roadways. The DTM hillshade of Elkton West 7.5-minute quadrangle is shown on the right. The DTM was created in ArcGIS's Spatial Analyst.

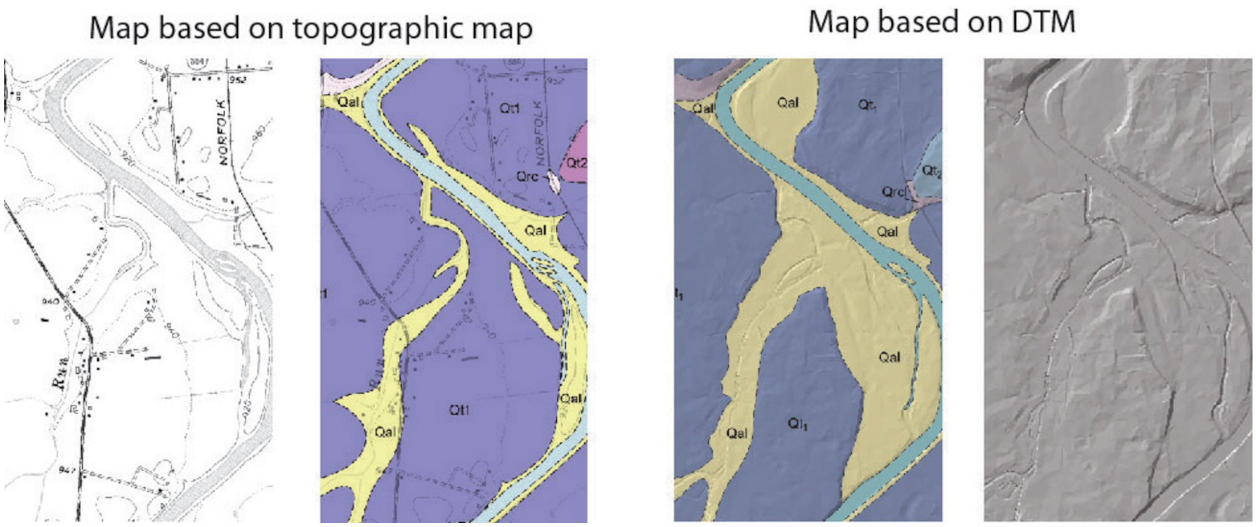

Figure 2. An example of a refinement that the DTM hillshade provided is visible in the comparison of the alluvium as mapped from the topographic and soils maps (second image from left) and the alluvium as mapped from the DTM hillshade (third image from left). One can see that the alluvium is much more extensive on the map based on the DTM hillshade. This revision was confirmed in the field.

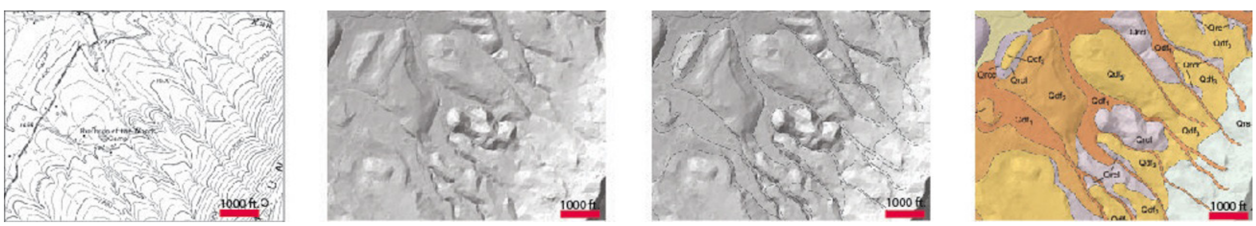

Figure 3. Three generations of debris-flow deposits (shown in shades of yellow and orange on the right-most image) and areas of residuum (gray areas) are distinguishable on the DTM hillshade; interpreted geologic contacts are shown on the DMT image that is second from the right. These deposits are difficult to distinguish from one another on the topographic map (left-most image).

Features From Coastal Plain Mapping in Providence Forge 7.5-Minute Quadrangle

Mapping in the Providence Forge 7.5-minute quadrangle has also benefited from detailed elevation data collected for rectification of Virginia's orthoimagery. Shaded relief maps generated from these elevation data enable correlation of Pleistocene terraces and underlying marine and nearshore facies of older stratigraphic units, previously difficult to resolve. Scarp and terrace morphology, which generally follow consistent elevations, can be further refined with the use of shaded relief maps.

The surface raster (the DTM) developed for this quadrangle was classified using the natural breaks (Jenks) method in ArcGIS. The natural breaks classification scheme works well with these data because it selects the most suitable class ranges by finding clusters of similar elevations over the entire range of the data set. Several terrace scarps are visible on the natural-breaks shaded DTM (fig. 4). One of the most prominent terraces has a flat surface ranging up to 48 ft elevation. This corresponds to the elevation for the Shirley Alloformation (Qsh) identified elsewhere on the Coastal Plain using traditional mapping techniques (Mixon and others, 1989). In Figure 5, the terraces corresponding to the Chuckatuck Alloformation (Qc), Tabb Alloformation, Sedgefield Member (Qts), and the Shirley Alloformation (Qsh) are identified. This has been confirmed by field work, including geologic borings (Gilmer and Berquist, 2011).

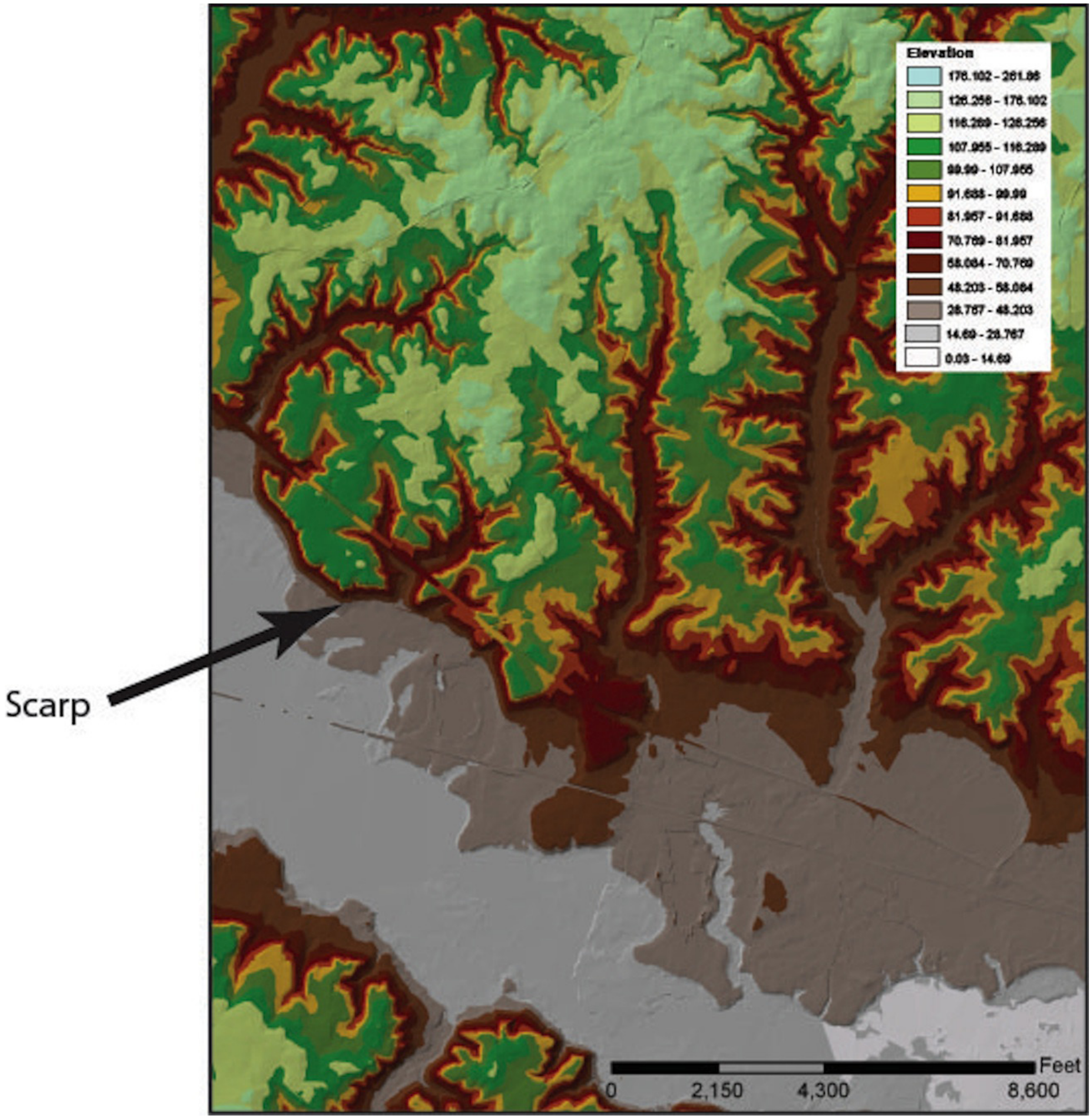

Figure 4. DTM created in ArcGIS and shaded by color ramps using the natural breaks classification scheme, showing several terrace scarps. Elevations are in feet above sea level. Shirley Alloformation occurs beneath the 48-ft level, shown here in light brown.

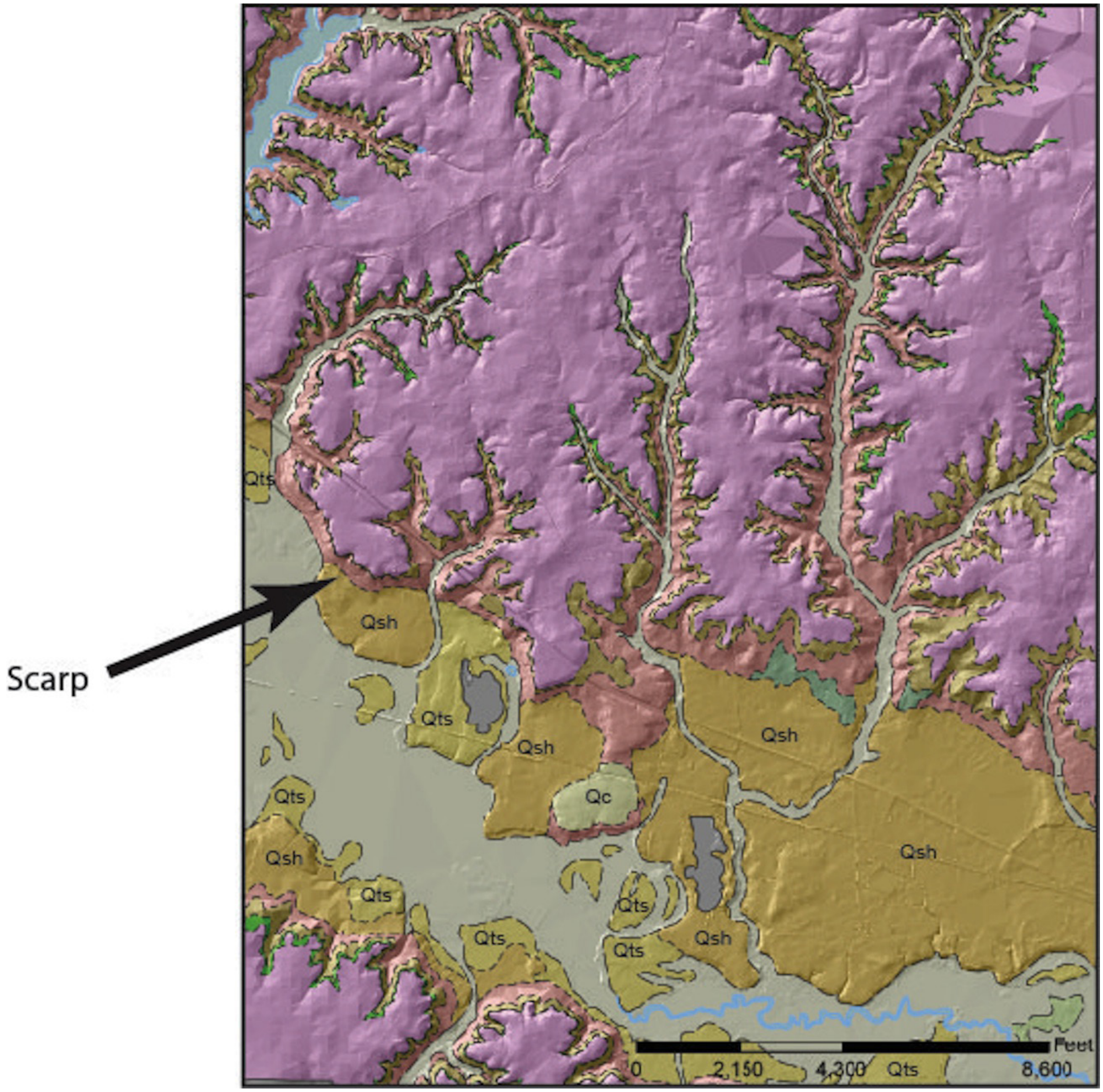

Figure 5. Terraces corresponding to the Chuckatuck Alloformation (Qc; yellow areas), Tabb Alloformation, Sedgefield Member (Qts; pale orange) and the Shirley Alloformation (Qsh; orange) were identified on the DTM and confirmed by field work, including hand augering and geologic borings.

Limitations of DTMs Created From Orthoimagery Data

Although DTMs created from orthoimagery data are extremely useful for identifying features, they do have significant limitations. Their primary purpose is to rectify imagery, not to serve as a basemap for geologic mapping. This must be considered when attempting to do any quantitative analyses using the DTMs. DTMs created from orthoimagery data are not as detailed as DTMs generated from LiDAR data.

Areas with densely spaced infrastructure, such as roads, railroads, and buildings, have many more breaklines and masspoints than areas with little development and, therefore, show more detail. Also, areas with significant changes in slope, such as ridges and areas with significant hydrography, have more breaklines than areas that are flat-lying or lack streams or lakes. Therefore, some areas have more elevation control than others (fig. 6). This makes it difficult to quantify the accuracy of the DTM generated from elevation control data associated with the orthoimagery.

Another challenge DGMR faced in using the DTMs is that in some quadrangles the data collected for elevation ground control is at different scales. For example, the portion of Providence Forge quadrangle in New Kent County is at a scale of 1 inch = 100 ft, whereas the portion in Charles City County is at a scale of 1 inch = 200 ft. This variation in scale can cause edge effect errors, leaving some areas without useful data. In many cases, nothing substitutes for "boots-on-the-ground" field work. Features such as narrow debris flows are sometimes not resolvable on the DTM hillshade or the topographic map. Only field traverses enable the geologist to map the true extent of these features.

Conclusions

High-resolution DTMs have been very useful to DGMR geologists for delineating both geomorphic and geologic features. DGMR now examines the DTMs for every mapping project. The higher-resolution and more current information provided by this tool enable the geologist to plan their field work in order to evaluate observations made from these DTMs. In an ideal world, LiDAR data would provide this service and enable much more quantitative analysis of an area, but LiDAR data are not available for most areas. The DTMs based on elevation control from orthoimagery are a good substitute until we can obtain statewide LiDAR coverage.

Additional Information

Additional information is available on the poster presented at the DMT meeting (fig. 7) or by contacting the authors.

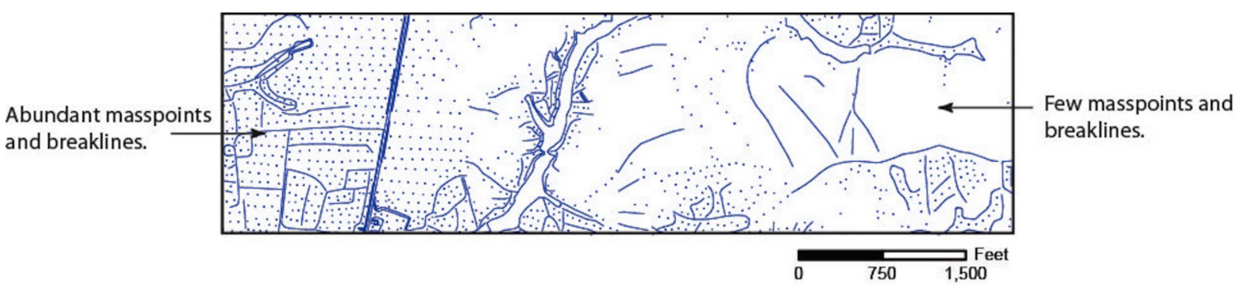

Figure 6. Masspoints and breaklines for a part of the Providence Forge quadrangle.

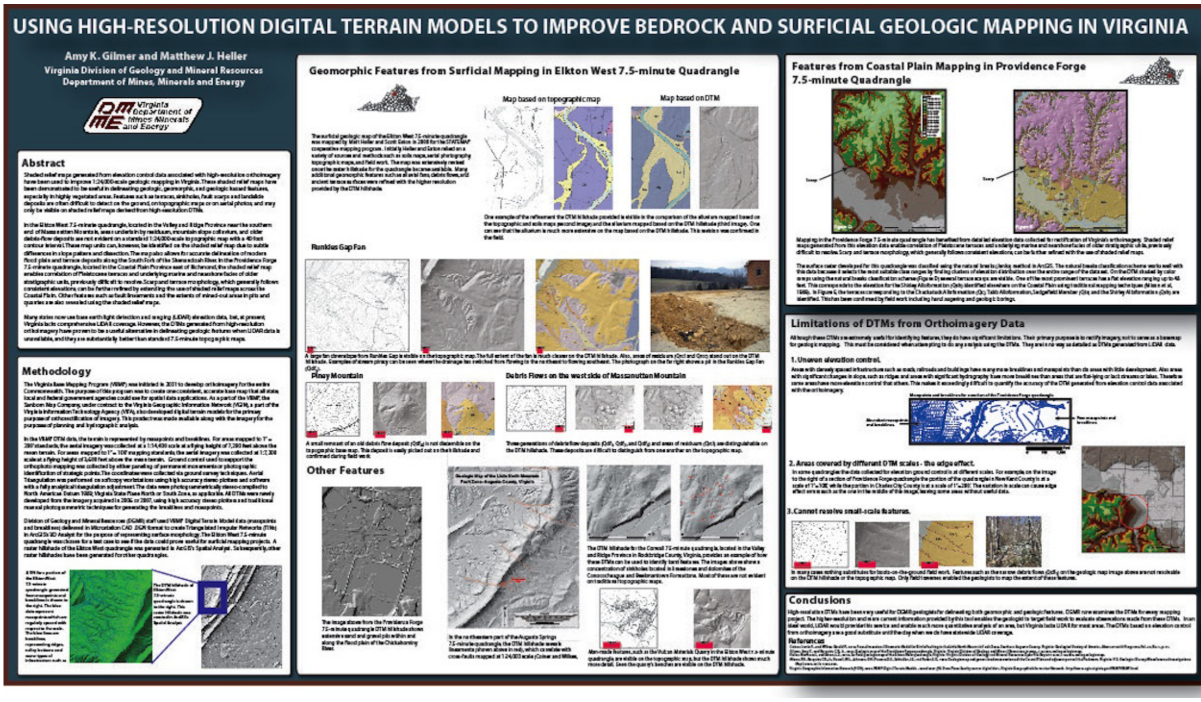

Figure 7. Poster entitled "Using High-Resolution Digital Terrain Models to Improve Bedrock and Surficial Geologic Mapping in Virginia," presented at the Digital Mapping Techniques 2011 workshop in Williamsburg, Virginia. A high-resolution version of this poster is available for download at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT11_Gilmer.pdf*.

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Laying the Foundation for a Dynamic Geologic Map of Virginia

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Abstract

The Virginia Division of Geology and Mineral Resources (DGMR) is taking several approaches to expand access to accurate and up-to-date geologic maps of Virginia. In 1996, DGMR began converting existing geologic maps to digital format in order to accommodate increased demands for digital data. This effort has been supported by the U.S. Geological Survey's (USGS) STATEMAP program since 2003. In 2009, DGMR began migrating geologic maps of multiple scales and generations to a multimap enterprise ArcSDE geodatabase. This endeavor includes transferring the 1993 Geologic Map of Virginia from shapefile format to a geodatabase format based on the USGS National Cooperative Mapping Program's data model, "NCGMP09" (*http://pubs.usgs.gov/of/2010/1335/pdf/usgs_of2010-1335_NCGMP09.pdf*). This geodatabase design includes both feature-level metadata and symbology. The integration of digital mapping, at a variety of scales within the State geologic map, will allow customers to find the most accurate and current digital geologic data for a given area.

DGMR will also begin providing access to georeferenced images of published geologic maps in a Web map service utilizing Esri's ArcGIS Image Server. This allows ready access to all published mapping and gives users the opportunity to compare different geologic interpretations reflected on geologic maps from different eras of mapping.

By enabling the geodatabase design model to interact with the DGMR online store and map download site, DGMR will be able to distribute geologic maps and information in a variety of standard and flexible formats. Access to these data products will be made available through the Department of Mines, Minerals and Energy's Web map application, spatial data download site, and published Web map services.

Introduction

Since the publication of the 1841 "Geologic Map of Virginia and West Virginia" (Hotchkiss, 1879), the State of Virginia has seen multiple generations of statewide geologic interpretations. Recently, geospatial advances have allowed geologists to deliver mapping products more efficiently. Such advances have enabled DGMR to provide more accurate and current maps, including offering a variety of digital products. DGMR has taken some initial steps to improve access to geologic map data from current individual map storage systems into fully interactive map services. This includes creating a "foundation," or host map that will house a system to access geologic map data.

Foundation Structure

Since Virginia only has statewide geologic map coverage at the 1:500,000 scale, DGMR decided the foundation for its digital products would be the 1:500,000-scale 1993 Geologic Map of Virginia (DGMR, 1993; fig. 1). The digital version of this map was created by digitizing the paper map to a shapefile, which was then converted into a file geodatabase. In addition, the geodatabase version contains feature classes representing various aspects of the 1:500,000-scale paper map, including:

- Map unit polygons
- State boundary and shoreline
- Contact lines
- Fault lines
- Dikes and thin-bed lines.

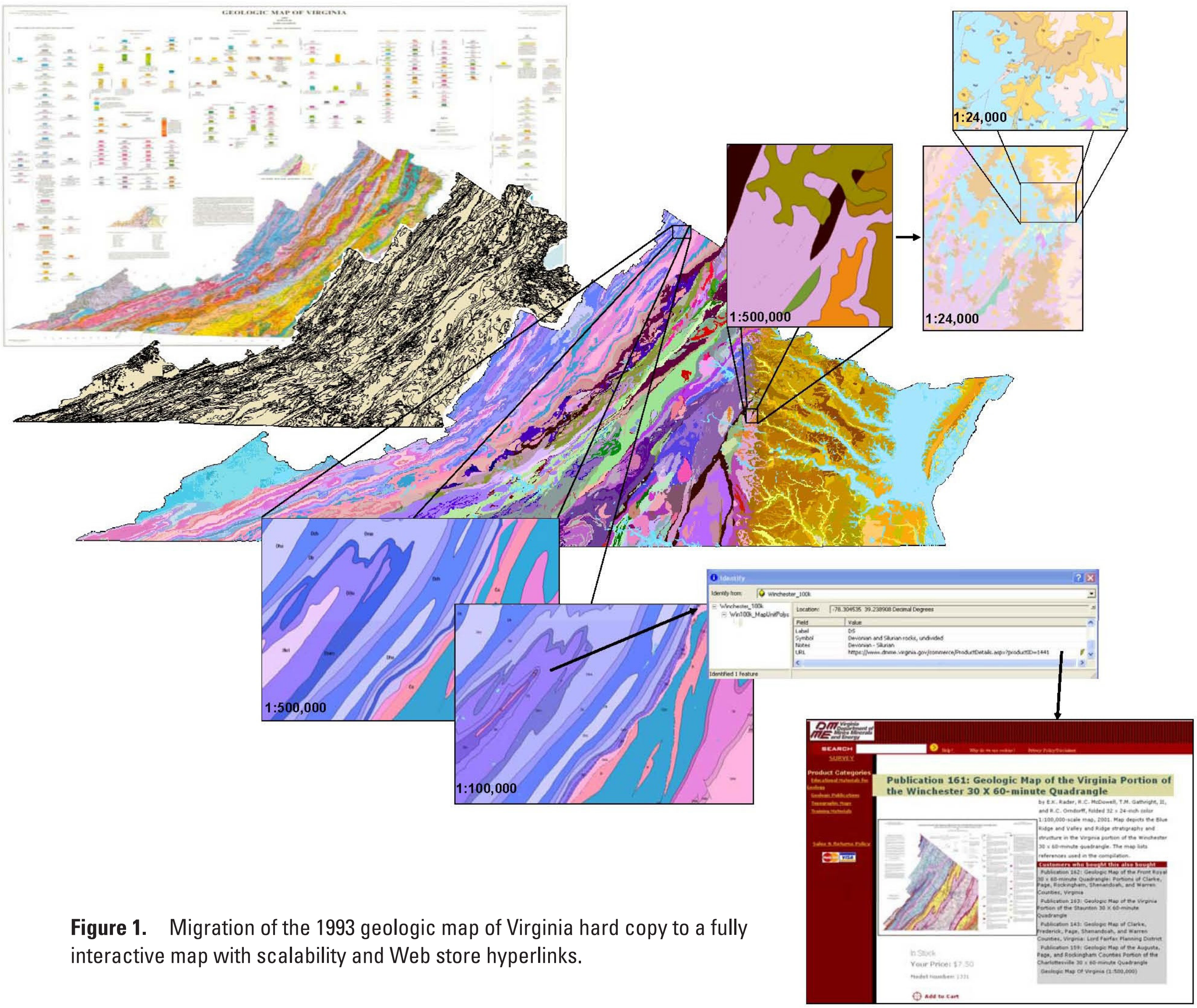

Figure 1. Migration of the 1993 geologic map of Virginia hard copy to a fully interactive map with scalability and Web store hyperlinks.

Each feature class contains assigned representations from the Federal Geographic Data Committee's (FGDC) Digital Cartographic Standard for Geologic Map Symbolization (Federal Geographic Data Committee, 2006). The map unit polygons feature class contains two sets of color representations: a primary lithology representation and a geologic age representation. Also included in the geodatabase are annotation classes that label each geologic unit using a geologic age font. The digital version of the 1:500,000-scale geologic map of Virginia accommodates multiple functions for interactive use, such as:

- Query capabilities
- Seamless scalability for access to larger scale maps
- Attributes of map unit polygons and faults
- Hypertext links to DGMR's Web store.

The foundational map and functionality were made available in ArcExplorer, at *http://explorer.arcgis.com/?open=3519ff0d314245e3ab5728c3749a5b44*.

Building on the Foundation

DGMR will publish the basemap geodatabase to an ArcSDE Enterprise Geodatabase. In the future, geologic maps of other scales will also be incorporated into the ArcSDE Enterprise Geodatabase and will be accessible as Web map services (fig. 2). ArcSDE will provide dynamic map capabilities and versioning for multiauthor use, but will also have multimap capacity for scalability functions and a service-oriented architecture. This ArcSDE geodatabase will host DGMR's collection of file geodatabases that hold maps of multiple scales and generations, and distribute these features to application services.

Incorporating ArcSDE will allow DGMR to convey geologic mapping data through two different portals: a Web map application supplied by the Virginia Department of Mines, Minerals and Energy (DMME) and through Esri's ArcExplorer Online. The Virginia DMME is currently

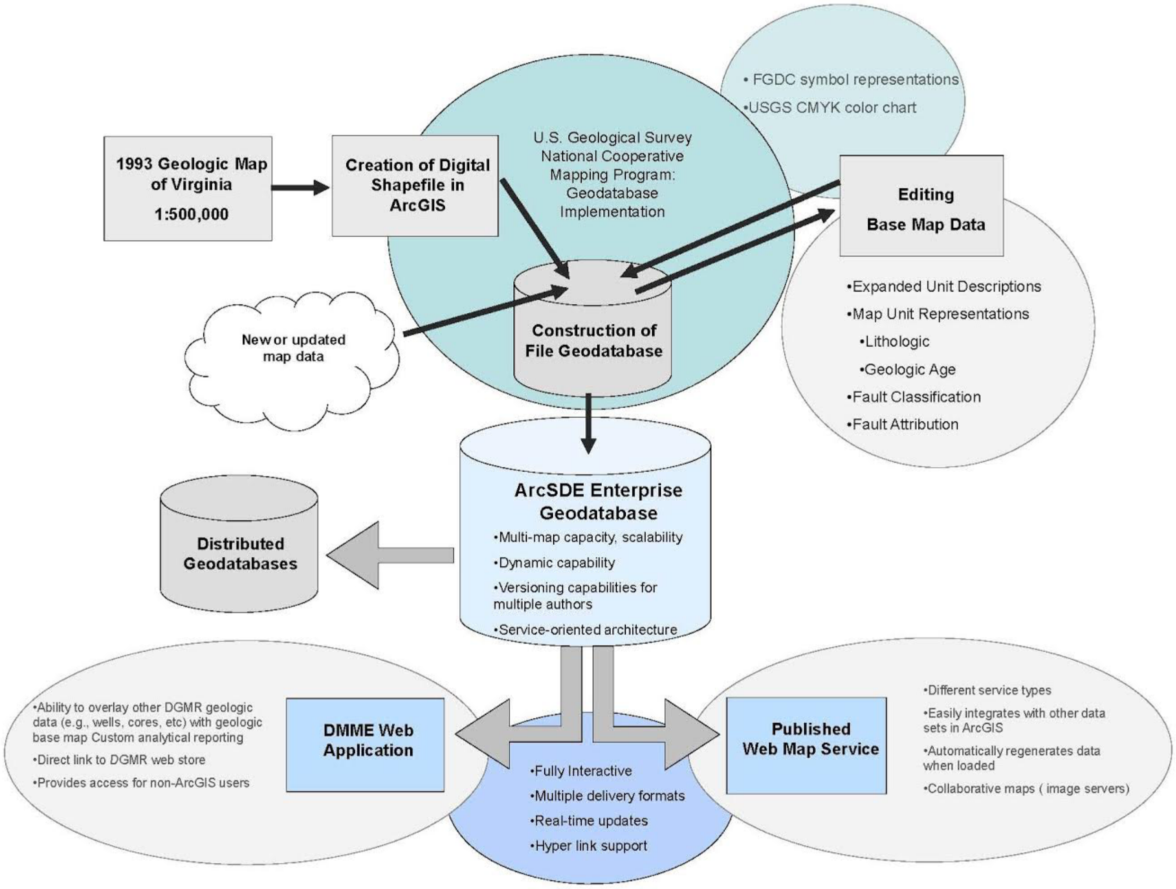

Figure 2. Work flow diagram displaying process for providing geologic maps through ArcSDE Enterprise Geodatabases.

building a department-wide Web map application for spatial data supplied by its multiple divisions, including DGMR. The DMME Web application will be available in a Web browser, which will offer non-ArcGIS users the opportunity to navigate without ArcGIS. Web map service users will have access to the interactive geologic map, along with the capability of integrating other spatial data in ArcGIS. The service will automatically regenerate map updates from DGMR.

Esri's ArcExplorer Online will offer DGMR more local control of our published Web map services and will enable us to serve a variety of digital map products, including Web map services, map packages, browser maps, and shapefiles. With multiple methods to serve our mapping products, DGMR will be able to broaden customer outreach. Currently, DGMR provides an interactive map service, which can be found online at *http://explorer.arcgis.com/?open=3519ff0d314245e3ab5728c3749a5b44*.

Additionally, users will have the ability to view other DGMR geologic data, such as well and core data, and extract custom analytical reports. The Web map services will also provide users with direct links to DGMR's Web store for product purchasing at *https://www.dmme.virginia.gov/commerce/*. DGMR plans to provide all existing scanned geologic maps as georeferenced images using ArcGIS Image Server in both services. These maps are also available on the USGS's National Geologic Map Database Web site (*http://ngmdb.usgs.gov*). All delivery options point users in the direction of DGMR's online Web store for access to PDFs and hard copies of each map.

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Things You Used to Hate About Map Layout in Arc Have Changed: Attractive and Complete Maps Are Possible in ArcGIS!

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Introduction

Cross-section and stratigraphic column diagrams are important accessory information to many geologic maps. These diagrams are often included for illustrative and interpretive purposes, but their size and scale dimensions must match the geologic maps they accompany and, in order to be useful reference material, the diagrams must plot out on the final paper map at the exact size and scale intended. The authors decided to use the projected-space functionality of geographic information (GIS) software, namely Esri's ArcMap, to achieve this goal without having to employ any external illustration software. The map layout shown in figure 1, including all diagrams and insets, was constructed entirely in ArcMap (version 9.3). The cross sections are the same scale as the geologic map, which is 1:24,000, and print out on the paper map at the exact size at which they were intended to be shown. Similarly, the stratigraphic column prints out at its correct size and scale (1 inch = 100 feet (ft)).

Cross Sections

Step 1: Measure Cross Section and Build Frame to Scale in Arc

This method builds an idealized, mathematically "perfect" frame and corrects for several types of drafting errors, omissions, and inconsistencies that can be made by authors. It can also be used to change the scale and (or) vertical exaggeration of a cross section drafted on paper into a new one. For example, a diagram drawn at 1 inch:800 ft scale can be converted to the more standard 1 inch:2,000 ft, or a diagram drafted on paper with a vertical exaggeration of 2X for drafting convenience can be rescaled and then digitized with no vertical exaggeration to appear at true 1:24,000 scale on the finished map. The following directions are excerpted from Gooding, 2010 (S.E. Gooding, ed., Digital Open-File Geological Maps of West Virginia National Park Service Mapping Project Handbook (unpublished): West Virginia Geological and Economic Survey):

Horizontal Axis:

Measure cross-section location line (for example, the A-A′ line highlighted in red on the map layout shown in figure 1) on the geologic map to an accuracy of at least one-hundredth of an inch (0.01 inch) using a scale/drafting ruler or measure the line on the scanned, full-size tif image of the map in Photoshop. DO NOT measure the horizontal axis of the drafted cross section itself; it MUST be the location line from the map. Otherwise any drafting errors in the length of the cross section will be perpetuated.

Convert the real-world paper measurement of the cross-section location line into projected-space "ArcMap inches" by multiplying the measurement by 24,000. This will be the true length of the cross-section horizontal axis in ArcMap. For example, a cross-section line measuring 25.685 inches on the paper map or in Photoshop, when multiplied by 24,000, will be 616,440 inches in ArcMap-projected space.

Begin digitizing the cross-section frame in Arc:

1. Left click to start drawing the line of the horizontal axis.
2. Right click and choose "Direction/Length" from the floating menu.

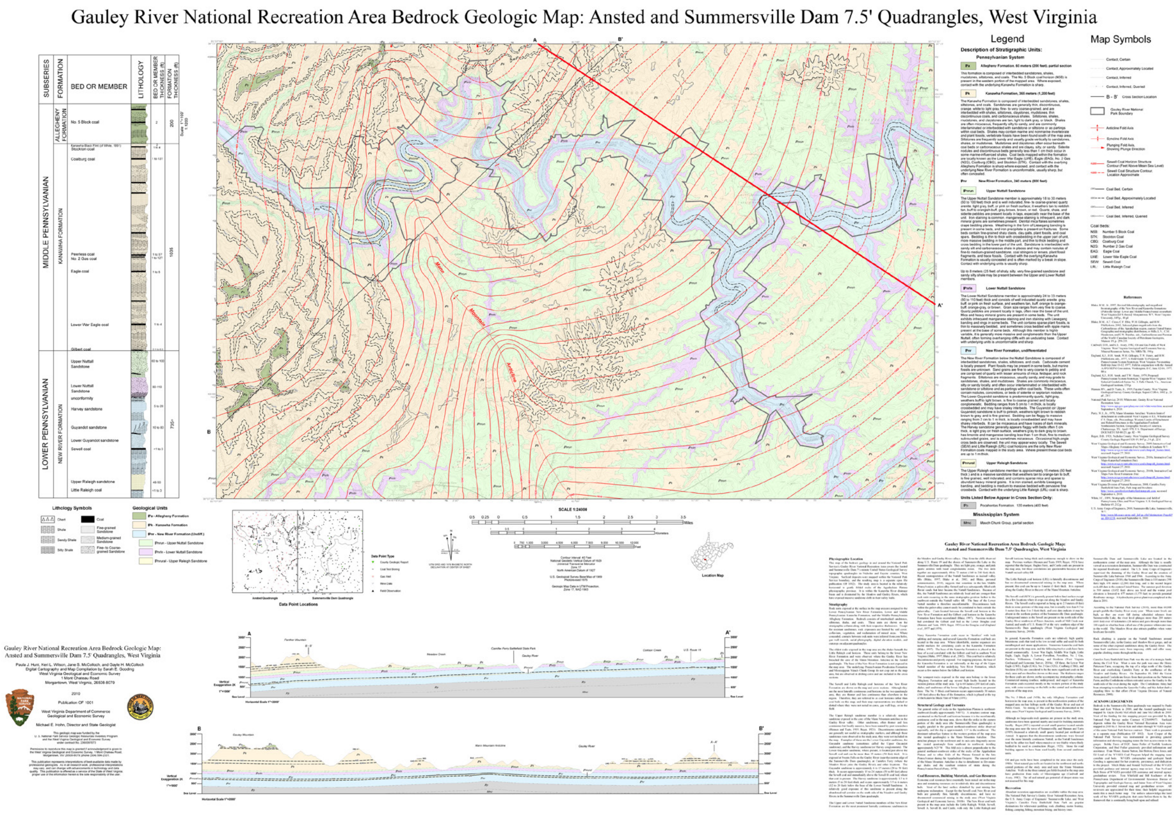


Figure 1. Low-resolution image of *Gauley River National Recreation Area Bedrock Geologic Map* (Hunt and others, 2010) layout, showing cross section A–A' highlighted in red for example of cross section digitizing process and overall layout construction and final cartography.

3. Enter "0" for Direction (straight horizontal) and "616,440 in" for Length in the dialog box. Be sure to type "in" for inches or it will default to units of the data frame, which in UTM projection would be meters.
4. Hit Enter and F2 keys to end the line (fig. 2).

Measure and Calculate the Vertical Axes:

Examine and measure vertical axes of the original diagram. Use idealized axes to account for and repair drafting errors, and perform any necessary re-scaling or changes in vertical exaggeration. Convert to projected-space "ArcMap inches" for the vertical axes and build an idealized frame in Arc-projected space to enclose all parts of the diagram, extending vertical axes up and (or) down if necessary to correct any drafting errors by the author.

For example, a cross section with no vertical exaggeration and an idealized vertical axis of 5,000 total vertical feet (add above and below sea level tics to get total feet) should measure 2.5 inches high on paper.

5,000 feet at 1 inch:2,000 feet = 2.5 inches high

Then, convert to ArcMap inches by multiplying by 24,000:

2.5 inches x 24,000 = 60,000 "ArcMap inches"

Draw Vertical Axes:

1. Left click to start drawing the line of the vertical axis. Snap to "End" of horizontal axis line.
2. Right click and choose "Direction/Length" from the floating menu.
3. Enter "90" for Direction (Straight Vertical) and "60,000 in" for Length in the dialog box.
4. Hit Enter and F2 keys to end the line.
5. Repeat for other vertical axis (fig. 2).

STEP 2: Create the Elevation Tic Marks

Use the "Divide" (now called "Split" in Arc v. 10) function on the Editor Toolbar to divide the vertical axis lines into equal segments for the elevation tics based on how many elevation tics will be needed. For example, the cross section shown in figure 3 uses five line segments.

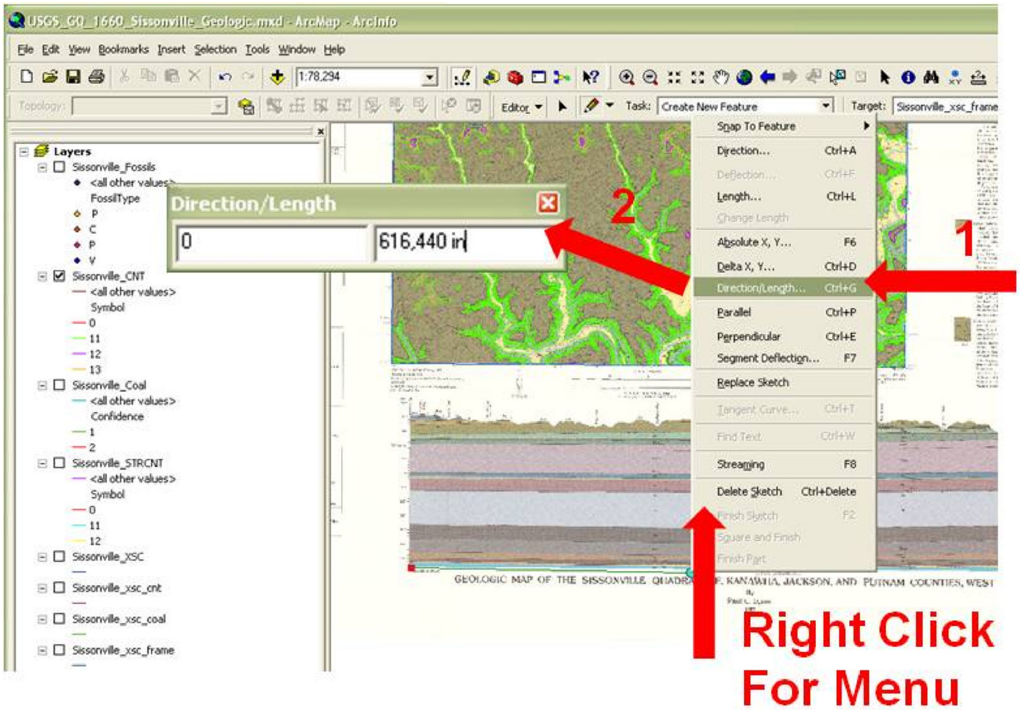
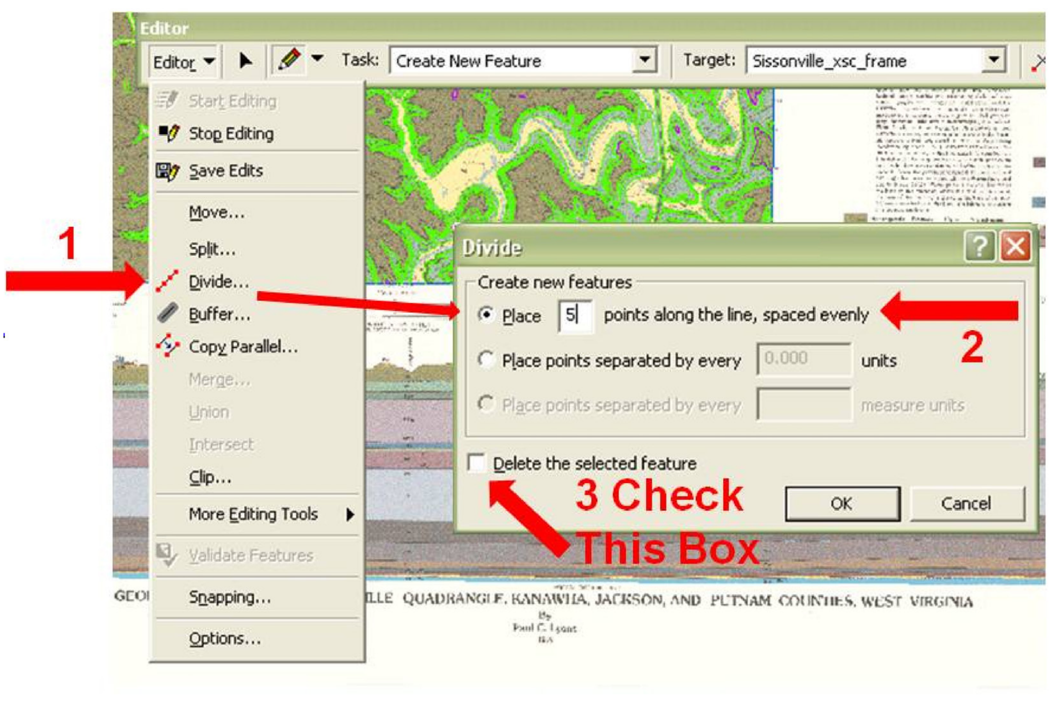
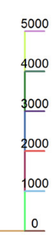


Figure 2. Cross sections, Step 1: Building the horizontal and vertical axes of the cross-section frame in Arc.



Are the scale and the brown line at the bottom needed or should I hide them?



STEP 2: Create the Elevation Tic Marks

Figure 3. Cross Sections, Step 2: Creating the elevation tic marks on the vertical axes.

Digitize the Elevation Tics: Use the "Direction/Length" floating menu option to digitize short tics at the end of each segment of the vertical axis, including the very top and bottom of the axis, so it looks like the example in figure 3. Use a direction of 180 for the tics on the left side of the frame and 0 on the right side. Use a length of 150 for all tics (go with default ArcMap units, not inches in this case).

Attribute all tic lines with the correct elevation. Use "0" for sea level. Use negative numbers for elevations below sea level. I used "–9999" for all other frame lines that did not need an elevation value, but a "NULL" value could also be used for labeling purposes on the final map.

STEP 3: Georeference Source Material and Digitize the Cross-Section Contact Lines and Label Points

Georeference a scanned image of a traditionally drafted cross section like the one shown in figure 4, using the matching elevation tics from the frame and the image. Then digitize the lines by hand or use raster-to-vector conversion tools.

Other ways to generate the cross-section linework include:

1. Bring in unscaled vector linework in Cartesian coordinates from CADD or Illustrator-type graphic programs and use Spatial Adjust tools to make the linework fit the frame in the same manner as the stratigraphic column example shown later in this paper.

2. The topographic profile for the cross section (fig. 5) shown on the map in figure 1 was constructed using the Cross Section Tool from Thoms (2005) written for ArcGIS. A shapefile containing the cross-section line, a digital elevation model of the topographic surface, and the geologic contact polygons from the map were input into the tool. The resulting shapefile is a to-scale polyline of the topography broken into segments representing each geologic unit at the surface. The rest of the cross-section lines were then digitized in Arc without first being drafted on paper, using known unit thicknesses, dip, fold axis locations, coal bed elevations, and other geologic information.

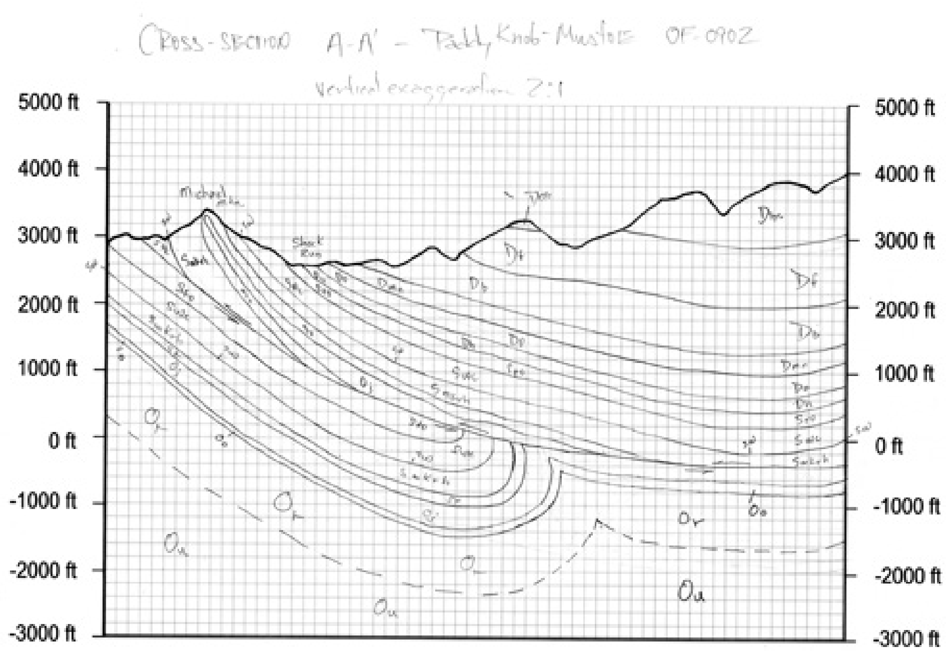


Figure 4. Cross Sections, Step 3(a): Example of a traditionally drafted cross section that has been scanned at high resolution and will be georeferenced in Arc to the frame built in Steps 1 and 2 for digital conversion.

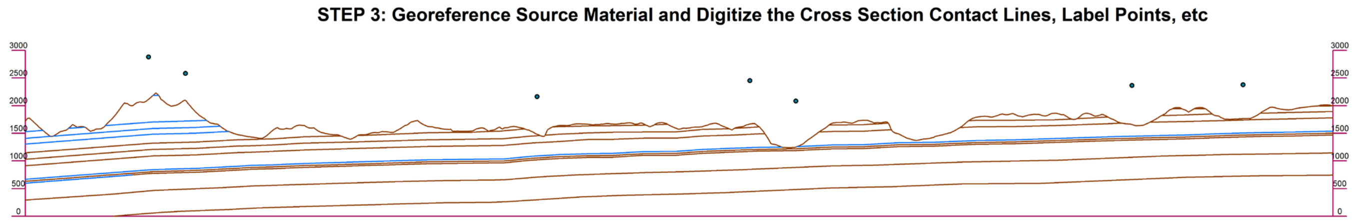


Figure 5. Cross Sections, Step 3(b): The digitized cross section, showing digitized lines for contacts (brown) and coal beds (blue), and digitized points for hovering topographic and structural labels. Line of section shown in figure 1.

This particular cross section in figure 5 also includes noncontact-forming coal beds as another line layer. Coal beds that DO form geologic unit contacts are included in the contact line layer of the cross-section geodatabase and will be used to form polygons in the next step. Lines in the contacts feature class are given attributes for whether they are a contact or fault and any unit abbreviation that may apply, such as coal bed name. Points for labeling cultural and structural features that “hover” over the cross section are also digitized during this phase in a “pointlabels” feature class (fig. 5).

Next, generate polygons from linework using “Line to Polygon” tools in Arc. The frame and contact lines feature classes are used to generate the polygons. It is recommended to create and verify Topology to make sure that there are no polygons that failed to form because of digitizing errors. Then add attributes for geologic units that match the accompanying geologic map, as shown symbolized in figure 6.

STEP 4: Cartography

Symbolize the geologic units, contacts, and coal beds with the same symbols used on the geologic map, with the exception that units which are only shown in the cross section are symbolized in shades of gray. Hovering point labels are symbolized with an appropriately sized italic font and a small white point symbol that will disappear against the paper on the map layout. Frame axis elevation tics are labeled and then converted into annotation that can be placed more appropriately on the map layout. Text blocks are placed on the map layout containing vertical and horizontal scale information. Figure 6 shows the finished cross section A–A’ at full scale, with all cartographic elements completed, as it appeared in the final publication (Hunt and others, 2010, shown in figure 1), in its own Data Frame on the map layout, locked at 1:24,000 scale.

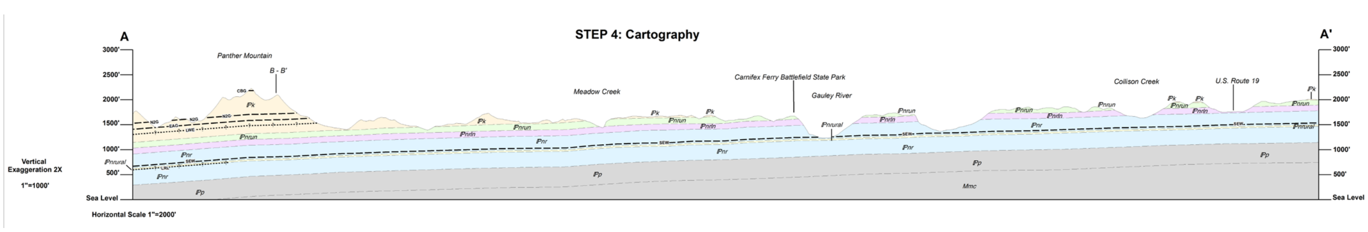


Figure 6. Cross Sections, Step 4: Generated polygons are given geologic unit attributes and symbolized to match the geologic map. Other digitized cross-section layers are shown here with final symbolization and cartography completed as it appeared in the final publication.

Stratigraphic Column

STEP 1: Build Frame, Georeference/Scale Source Material

First, a frame is built in Arc to the exact size of the desired finished stratigraphic column, following a similar procedure outlined for the cross sections. The projected space for the frame shapefile or geodatabase layer used should match the accompanying geologic map, for example, UTM NAD83, Zone 17, and the scale of the data frame should match that of the rest of the map layout, in this case 1:24,000.

For example, if the finished column on the map layout is desired to print out at 22 inches high, like the column shown in Hunt and others (2010) in figure 1, using a scale of 1:24,000 to match the map layout, multiply 22 in. by 24000 to get 528000 "ArcMap inches" and use this figure to construct the multiple parallel vertical axes of the column in Arc. Use the same formula to calculate the size of the horizontal frame lines, so they will print out at exactly 7 in. wide. 7 in. times 24000 will equal 96000 "ArcMap inches," and this figure will be used to construct the horizontal lines. Horizontal lines can be used at formation boundaries, as shown in figure 7, to serve as "tic marks" to help georeference the linework or images to the stratigraphic column frame.

Digitized linework from CADD, Illustrator, CorelDRAW, and other graphic programs with Cartesian coordinates can be imported and converted to a shapefile, and then "Spatial Adjust" tools can be used in Arc to fit the linework to the scaled, projected-space stratigraphic column frame. Bare, wire-frame linework should be imported, as shown in figure 7, to exclude or delete all vectorized fills and patterns. These will be replaced with polygon fill symbols at a later stage. Published or hand-drafted stratigraphic columns, such as the one used here from Englund and others (1986), can be scanned and imported as image files and georeferenced to the frame using formation boundary lines, known marker beds, or by using the scale bar on the diagram to re-scale the raster image to a section of the frame and then moving it into place. Complete or partial diagrams can be used for this, or a column can be compiled from multiple scanned diagrams or a mix of raster and vector source materials, as shown in figure 7.

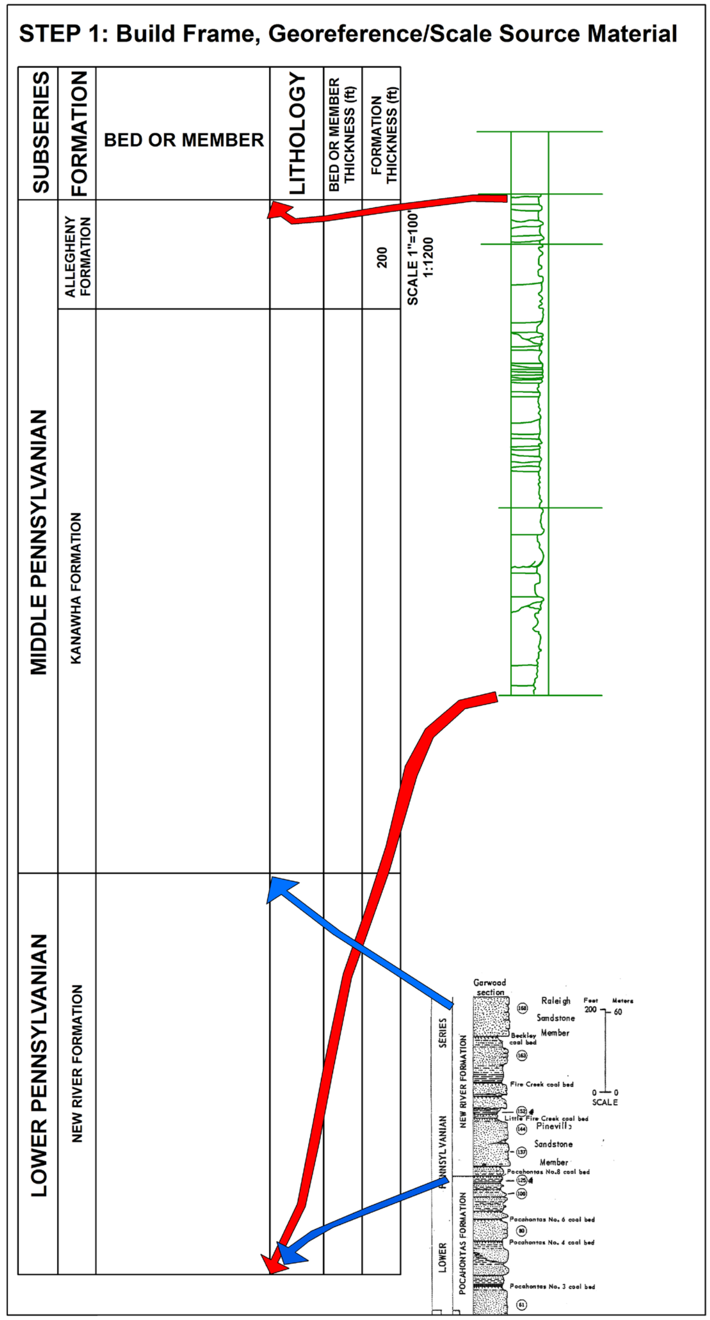


Figure 7. Stratigraphic Columns, Step 1: The column frame is built in Arc, so raster and vector source material can be georeferenced or Spatial Adjusted to it to compile a column specific to the accompanying geologic map.

STEP 2: Digital Linework and Points – Edit Spatial Adjusted Linework, Raster-to-Vector Conversion, and Regular Digitizing

Once the raster and (or) vector source material is scaled and georeferenced, the weathering profile and empty block outlines of the lithologic units are digitized and (or) edited to create the column, taking care to snap line ends to the frame and to each other, so that polygons will form correctly in the next step. Lines are given attributes for cartographic purposes, so that cross beds and other special features will have a different line style from unit contacts. Specialized symbology, such as cross-bed lines, unconformities, and the chert layer triangle symbols near the top of the column (fig. 8), had to be digitized literally, because no symbols for these exist in the Esri palettes.

Point features, such as fossils, could also be digitized at their locations along the column, and custom fossil point symbols could be used to symbolize these features. Point labels are also digitized in another point feature class at their correct locations in the "Bed or Member" and "Thickness" sections of the column and labeled with bed names and unit thickness to later annotate the column by converting into an Annotation Layer (fig. 8).

STEP 2: Digital Linework and Points

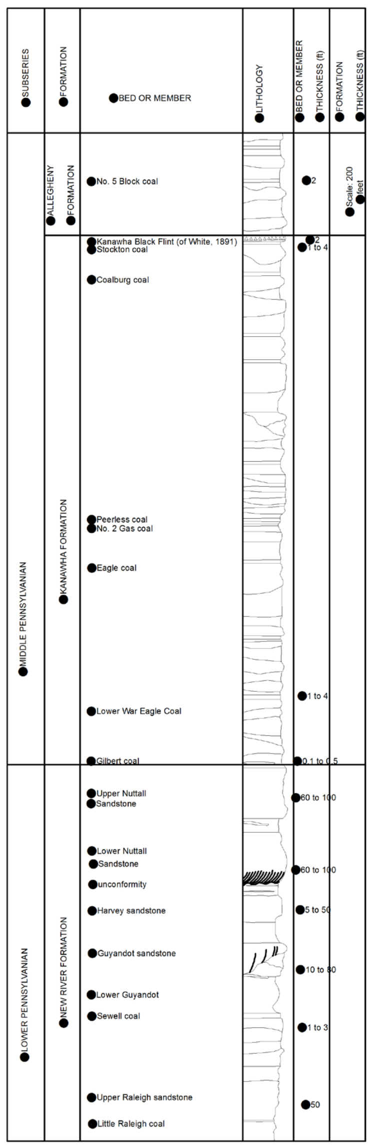


Figure 8. Stratigraphic Columns, Step 2: Linework is edited from vector source material, or digitized from raster sources, and given attributes for desired line style. Points are digitized for labels for frame, bed names, thicknesses, other notations, and fossil symbols.

STEP 3: Polygons and Attributes: Generate Polygons From Lines

Once linework for the column is completed, polygons are generated for the lithologic units and assigned attributes for geologic unit (for example, Pnr, Pk) and lithology (for example, shale, sandstone, coal). Three types of shale and three types of sandstone were used as attributes to increase the visual interest of the stratigraphic column (figs. 9 and 10).

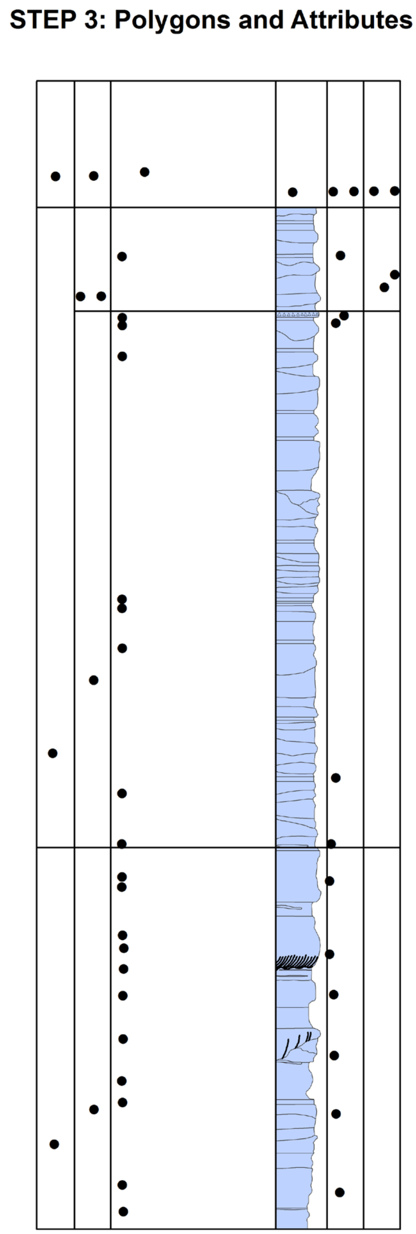
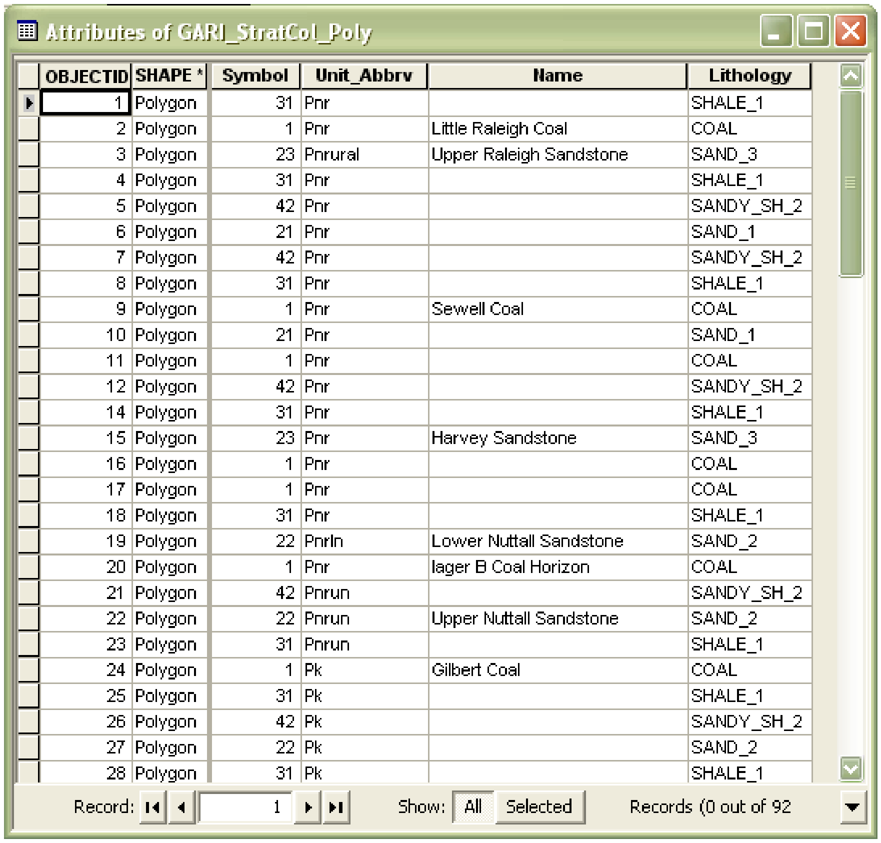


Figure 9. Stratigraphic Columns, Step 3(a): Polygons were generated (shown in blue) and given unit attributes to match the accompanying geologic map and lithology attributes for lithology polygon fill symbols.



Attributes of GARI_StratCol_Poly

OBJECTID	SHAPE *	Symbol	Unit_Abbrv	Name	Lithology
1	Polygon	31	Pnr		SHALE_1
2	Polygon	1	Pnr	Little Raleigh Coal	COAL
3	Polygon	23	Pnrural	Upper Raleigh Sandstone	SAND_3
4	Polygon	31	Pnr		SHALE_1
5	Polygon	42	Pnr		SANDY_SH_2
6	Polygon	21	Pnr		SAND_1
7	Polygon	42	Pnr		SANDY_SH_2
8	Polygon	31	Pnr		SHALE_1
9	Polygon	1	Pnr	Sewell Coal	COAL
10	Polygon	21	Pnr		SAND_1
11	Polygon	1	Pnr		COAL
12	Polygon	42	Pnr		SANDY_SH_2
14	Polygon	31	Pnr		SHALE_1
15	Polygon	23	Pnr	Harvey Sandstone	SAND_3
16	Polygon	1	Pnr		COAL
17	Polygon	1	Pnr		COAL
18	Polygon	31	Pnr		SHALE_1
19	Polygon	22	Pnrln	Lower Nuttall Sandstone	SAND_2
20	Polygon	1	Pnr	Iager B Coal Horizon	COAL
21	Polygon	42	Pnrun		SANDY_SH_2
22	Polygon	22	Pnrun	Upper Nuttall Sandstone	SAND_2
23	Polygon	31	Pnrun		SHALE_1
24	Polygon	1	Pk	Gilbert Coal	COAL
25	Polygon	31	Pk		SHALE_1
26	Polygon	42	Pk		SANDY_SH_2
27	Polygon	22	Pk		SAND_2
28	Polygon	31	Pk		SHALE_1

Record: 1 Show: All Selected Records (0 out of 92

Figure 10. Stratigraphic Columns, Step 3(b): A screen capture of the attribute table for the stratigraphic column unit polygons, showing attribute fields for Symbol, Unit Abbreviation, Name, and Lithology.

STEP 4: Cartography: Putting it All Together...

Polygons then were symbolized based on lithology, using standard USGS symbol polygon pattern fills available in the Esri symbol palettes. The chert symbol and legend patch had to be created by hand since there was no symbol for this in the Esri palettes. Polygons were also symbolized based on geologic unit color to match the accompanying geologic map. The color layer was placed under the pattern fill layer, and the pattern fill layer was given transparent backgrounds so the color would show through the pattern.

Point labels were converted into an Annotation Feature Class for advanced label placement and font formatting. Fossil point locations were given fossil symbols imported as bitmaps from the Federal Geographic Data Committee (FGDC) symbol files that accompany the FGDC's *Digital Cartographic Standard for Geologic Map Symbolization* (FGDC, 2006).

Figure 11 shows the finished stratigraphic column at full scale, with all cartographic elements completed, as it appeared in the final publication. The final stratigraphic column is inserted into the overall map publication layout in its own Data Frame, locked at 1:24,000 scale (fig. 1).

Text and Legend

Large text blocks are first formatted in Microsoft Word, then inserted into the Arc layout as objects. This allows advanced text formatting to be used, such as employing different fonts, text sizes, and styles in a single block of text, using multiple text columns and hanging indents, and formatting individual paragraphs in different ways. There is a maximum single-page size limit of 13 x 13 inches for the Word object that Arc will accept, so this large block of text in figure 1 is

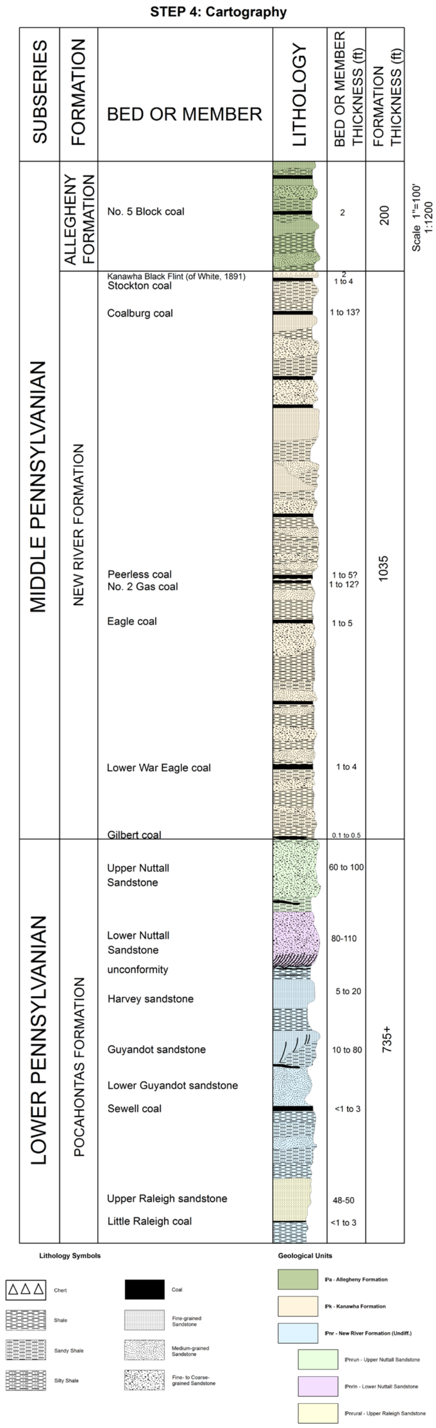


Figure 11. Stratigraphic Columns, Step 4: This shows the finished stratigraphic column with all cartographic elements completed, as it appeared in the final publication. Column units have been symbolized for both geologic map unit (color) and lithology (pattern). Labels have been converted into an Annotation layer for advanced placement and formatting.

actually two objects placed side by side in the map layout. A live link is maintained to the inserted text object, so any edits made to the text in Word will also immediately appear on the Arc layout once the document is saved.

Standard Arc legend tools were used to create the overall legend, then it was converted into graphics, and individual components were edited and arranged separately. Blocks of formatted text were copied and pasted in for the geologic unit descriptions. Standard Arc scale bars and text objects were used (fig. 1), and three separate Data Frames contain the Location Map, Data Point Locations inset map, and a custom-drawn north arrow showing the magnetic declination of the topographic base map.

A full-sized version of this map was shown during "Map Blast" at DMT'11 (see figure 12). It also is available as a publication from WVGES (Open File 1001) (Hunt and others, 2010) or from the National Park Service (GRI Source Map 75478 GARI). The full set of instructions for measuring and constructing cross sections (Gooding, 2010) can also be downloaded from the DMT Web site (*http://ngmdb.usgs.gov/Info/dmt/DMT11presentations.html*) or is available from the author upon request.

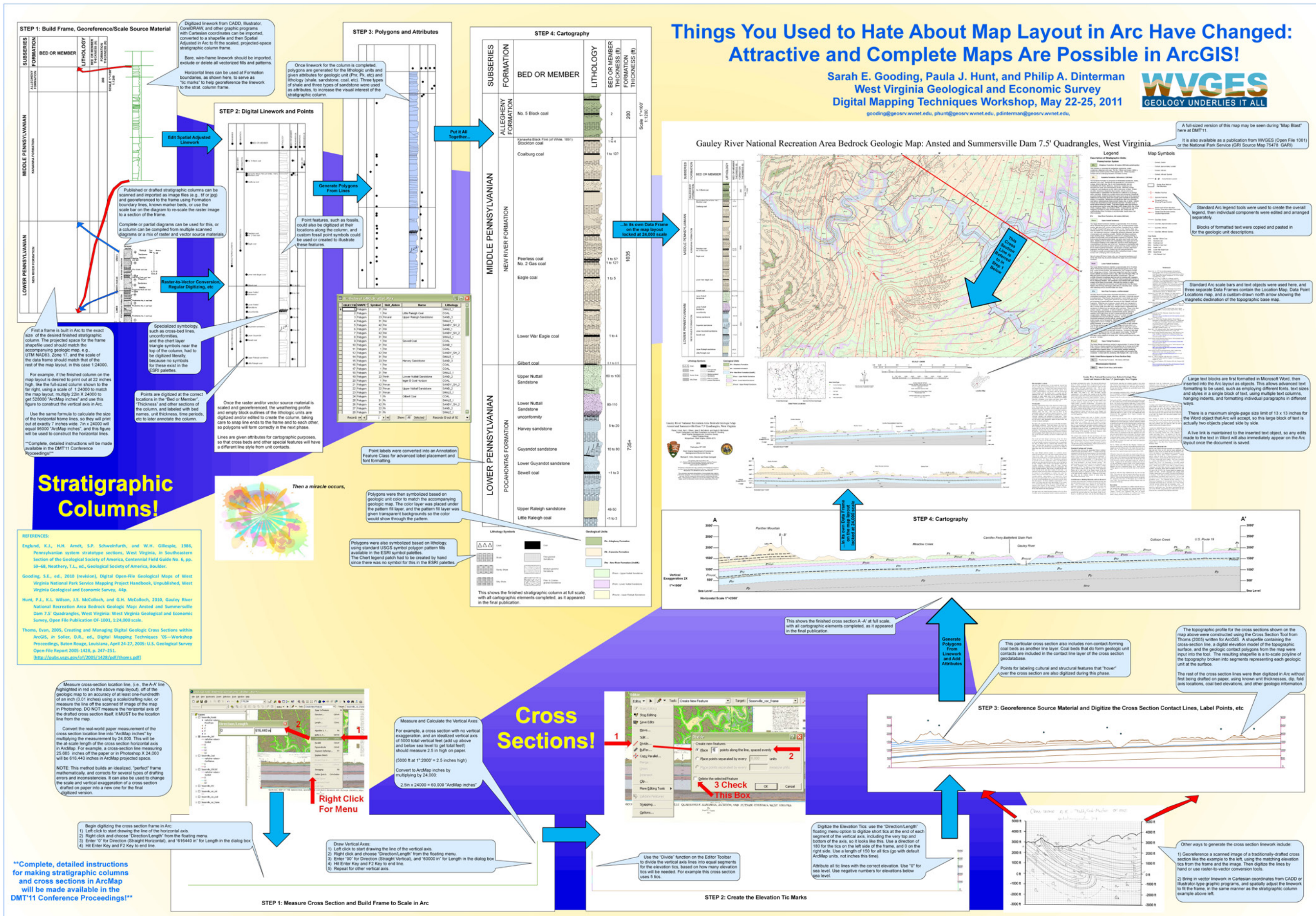


Figure 12. A page-sized version of the original poster as it appeared at the Digital Mapping Techniques '11 Workshop, May 22–25, 2011, in Williamsburg, Virginia. It can be downloaded from the DMT Web site, *http://ngmdb.usgs.gov/Info/dmt/DMT11presentations.html*.

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Federal Geographic Data Committee (FGDC) [prepared for the FGDC by the USGS], 2006, FGDC digital cartographic standard for geologic map symbolization: Reston, Va., FGDC Document Number FGDC-STD-013-2006, 290 p., 2 pls., *http://ngmdb.usgs.gov/fgdc_gds/geolsymstd.php*.

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Using the Magellan MobileMapper 6 With ArcPad 10 in the Field

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Introduction

The West Virginia Geological and Economic Survey (WVGES) is attempting to transition from traditional field mapping methods to the use of digital geographic information system (GIS) devices in the field in order to increase efficiency and productivity. WVGES currently uses various global position system (GPS) devices as well as the more powerful MobileMapper™ 6 unit. This paper presents a review of the MobileMapper 6 running Esri's ArcPad version 10. Two MobileMapper 6 devices were available for hands-on demonstration at the Digital Mapping Techniques '11 Workshop held in Williamsburg, Virginia, in May 2011, where this evaluation was presented in poster format (see poster at *http://ngmdb.usgs.gov/Info/dmt/DMT11presentations.html*).

Hardware

Specifics of the MobileMapper 6 Unit

The MobileMapper 6 (sold by Ashtech Products) used by the WVGES is a handheld personal data assistant (fig. 1). Ashtech, formerly Magellan Pro, started marketing a newer unit, the MobileMapper 10, in May 2011. The MobileMapper 10 was not tested by WVGES, but some details of the newer unit are provided here as it will likely replace the older MobileMapper 6 in the near future. The MobileMapper 6 was still available as of June 2011, but its continued availability is unknown.

Both units use the Microsoft Windows Mobile operating system with Office Mobile (Word, Excel, and PowerPoint) included. The MobileMapper 6 runs on two AA batteries, and two rechargeable batteries last 2 to 8 hours, depending on the number and type of layers open in ArcPad. The MobileMapper 6 has an integrated 2 megapixel camera and 128 megabytes (MB) of Flash memory with 64 MB of Random Access Memory (RAM). The MobileMapper 6 has a stated accuracy of 2 to 5 meters without post processing and less than 1 meter with post processing.

Figure 1. Magellan MobileMapper 6 in hand.

The newer MobileMapper 10 uses a lithium-ion battery pack, which reportedly has a 20-hour life with the device turned on. The MobileMapper 10 has a 3 megapixel camera, 256 MB of Flash memory, and 128 MB of RAM. The MobileMapper 10 has a stated accuracy of 1 to 2 meters without post processing and less than 0.5 meter with post processing.

As of June 2011, online prices for a MobileMapper 6 unit without mapping or differential correction software were $900 to $1,100 (Stakemill Measuring Systems). Differential correction software is available for an additional cost of approximately $500 (Stakemill Measuring Systems). The optional MobileMapper Field software is an additional $300 and was not tested by WVGES. The base cost of a MobileMapper 10 unit is approximately $1,200 and can be bundled with ArcPad 10 for a total of $1,640 (online prices as of June 2011 without taxes or shipping).

Hardware Pros

One of the major reasons WVGES chose the MobileMapper for field work was its capability to run ArcPad so that shapefiles created in the office can be used in the field, and those created in the field can be used in the office. Another reason this device was chosen over other field systems was its use of easily replaceable AA batteries. The MobileMapper 6 has several other useful features. The unit is ruggedized, relatively small, and relatively lightweight. It measures 2.5 inches (6 centimeters [cm]) wide by 6 inches (15 cm) long by 1 inch (2.5 cm) deep (fig. 1) and weighs 7.9 ounces (224 grams), making it relatively easy to carry in the field. However, the compact size of the overall device results in a screen that is relatively small (1.75 by 2.2 inches (4.5 by 5.6 cm). The MobileMapper can access satellites while kept in its case and will stay locked on satellites if the case is worn relatively high—on a shoulder strap, for example—as opposed to lower on a belt. An optional external antenna is available for approximately $30 (June 2011). The unit is capable of utilizing an optional secure digital (SD) memory card. WVGES uses 8 gigabytes (GB) SD cards in the units with generally good results.

Hardware Cons

As with any hardware, the MobileMapper 6 is not perfect. The unit's GPS is initially slow to lock onto satellites, but stays locked if the device is kept up or out. The 2 megapixel camera in the MobileMapper 6 is relatively slow and cumbersome. The camera may be adequate for scenery, but it has a relatively slow shutter speed and does not provide enough resolution for closeup detail, as shown in figures 2, 3, and 4. The device is not always recognized by a desktop or laptop computer when connected. If the MobileMapper is not initially recognized, the computer may have to be rebooted, the unit may have to be restarted, or both, before the two will communicate with each other. The unit does not hold the time and date in memory for very long after it is switched off and must be reset when turned back on. The unit will synchronize with the desktop computer's Microsoft Outlook program, updating all contacts and calendar items during every desktop connection unless the "Sync" settings are changed. The on-board memory could be larger, and the stylus provided with the unit is relatively small and easy to lose. The device reportedly does not work well with Windows 7, but this was not tested by the authors, who use Windows XP and Vista with the WVGES unit. Some of these drawbacks may have been improved in the newer MobileMapper 10, but that model was not tested by WVGES.

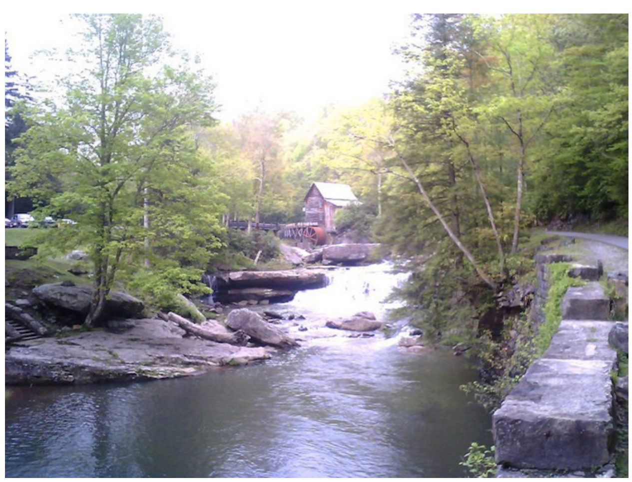

Figure 2. Photo taken with Magellan MobileMapper 6 in brighter light (Babcock State Park, WV).

Figure 3. Closeup photo taken with Magellan MobileMapper 6 (*Technocrinus* crinoids).

Figure 4. Scenery photograph taken with the Magellan MobileMapper 6 in low light (Babcock State Park, WV).

Software

Specifics of ArcPad 10

The WVGES MobileMapper units were running Esri's ArcPad 10, Version 10.0 SP1, Build 26 for this evaluation.

Software Pros

ArcPad 10 appears to be more stable than ArcPad 8, which initially was used by WVGES, but software errors still arise. Field data collected in ArcPad can be used in ArcMap by directly copying and pasting files from the device to the computer if all projection and other associated files are included. ArcPad 10 is capable of creating quick-fill forms; however, this feature was not tested by the authors as of June 2011.

Software Cons

A "Low Memory Error" occurs relatively often, which necessitates closing and re-opening ArcPad and re-acquiring satellites. Data check-in and check-out in ArcPad is error prone and cumbersome, but fortunately is unnecessary. Geotagged photographs are not easily placed in ArcMap. A memory card error sometimes occurs for no obvious reason, and occasionally a projection error occurs. The unit sometimes freezes while in edit mode and must be restarted. Turning on the track log may cause frequent low-memory errors and decreases battery life. Automatic sequential numbering of station numbers and a more automatic GPS track log using less memory would be useful features, if available. ArcPad is not ArcMap, and while the basic principles used in both programs are the same, the menus and toolbars are very different. Therefore the ArcPad learning curve may be relatively steep for some users.

Tips, Tricks, and Final Thoughts

A screen protector is recommended and used by WVGES, even though it decreases screen brightness. Unless versioning is important, checking ArcPad data in and out through ArcMap is not necessary and can be unwieldy. Shapefiles can be created on the unit in the field with ArcPad or in the office with ArcMap and can be transferred back and forth if all files associated with the shapefile (projection, database, etc.) are present. As usual, it is recommended to always test that shapefiles and other files transferred correctly and are usable *before* going into the field. Turning on the GPS before opening ArcPad generates an error, but using the GPS to set the time and date before starting ArcPad does not cause the same error. The device will maintain contact with satellites, in or out of its case, if it is worn on the shoulder or held away from the body. Frequent saves appear to cause low memory errors and may not be necessary because shapefile edits appear to be saved automatically. If a track log is desired, decreasing track log size before using the device in the field results in fewer memory errors. Even with its drawbacks, the MobileMapper is a viable and useful option for digital mapping in the field and will continue to be used by WVGES for its field-mapping projects.

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West Virginia Mine Pool Atlas Project—A Work in Progress

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Introduction

The Mine Pool Atlas project is a two-year study funded by the West Virginia Department of Environmental Protection (WVDEP) to evaluate abandoned coal mines as potential groundwater sources. Although West Virginia receives an average of 44.31 inches of precipitation each year (SERCC, 2011) and is considered to have an abundant supply of water, much of West Virginia's precipitation exits the State by way of its many streams. The remainder infiltrates the ground surface, but only a small amount of this water provides recharge to groundwater aquifers. One currently underutilized and often overlooked source of stored groundwater is abandoned coal mines (fig. 1). In order to develop an understanding of the potential of this water source for development, the West Virginia Geologic Survey (WVGES) is in the process of building a dynamic, interactive geographic information system (GIS) to portray the location of mine pools that could provide large volumes of water for various private, public, and industrial uses. The GIS will provide tools to estimate mine pool volumes in West Virginia.

Coal bed and mining information available from the West Virginia Geological and Economic Survey (WVGES) Coal Bed Mapping Program (CBMP) during the study was used to estimate the potential extent of mine flooding and the volume of water contained in each mine pool. Figure 2 shows the status of work being conducted by CBMP (B.M. Blake, West Virginia Geological and Economic Survey, unpub. data, 2011). (Note: After this presentation was given, the West Virginia Mine Pool Atlas was completed, in 2012, and is available for download at *http://www.wvgs.wvnet.edu/www/coop_rpts/coop_research.htm*.) The results of the study are presented in a PDF-format report that includes a series of maps showing information and statistics about each mine pool.

Figure 1. Water discharging from a power hole in the down dip end of the Summerlee mine in the Sewell coal bed emerges from a pipe at Dempsey, WV, where the water is treated. The mine is approximately 340 feet below the surface at this location (photograph by G.H. McColloch).

Project Overview

CBMP data are being used to determine which coal beds have mine pools capable of supplying large quantities of groundwater. Underground mining has taken place in 69 of 73 of the West Virginia's mineable coals, and information about underground mining in these coal beds is being incorporated in the CBMP GIS. Mine polygons of approximately 9,500 underground mines have been digitized from mine maps (fig. 3). In addition, a cropline, a structure contour of the elevation of the base of the coal bed, coal bed elevation raster data, and an isopach have been created for each coal bed.

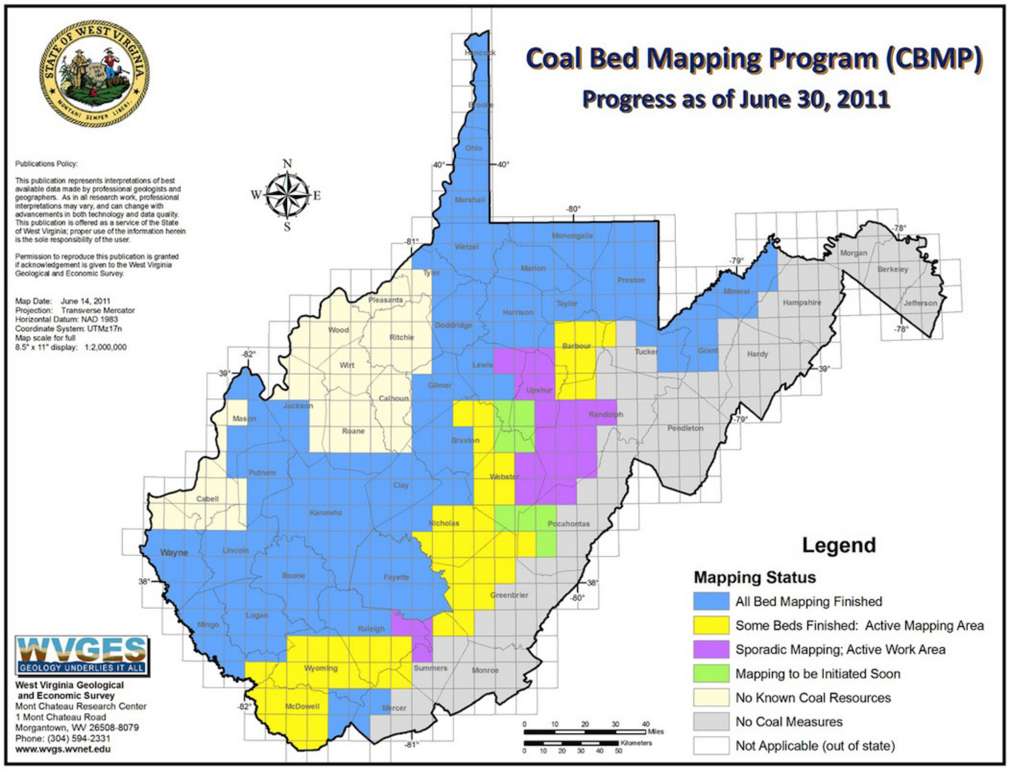

Figure 2. Status of coal bed mapping in West Virginia by the WVGES Coal Bed Mapping Program, projected to June 30, 2011 (B.M. Blake, West Virginia Geological and Economic Survey, unpub. data, 2011).

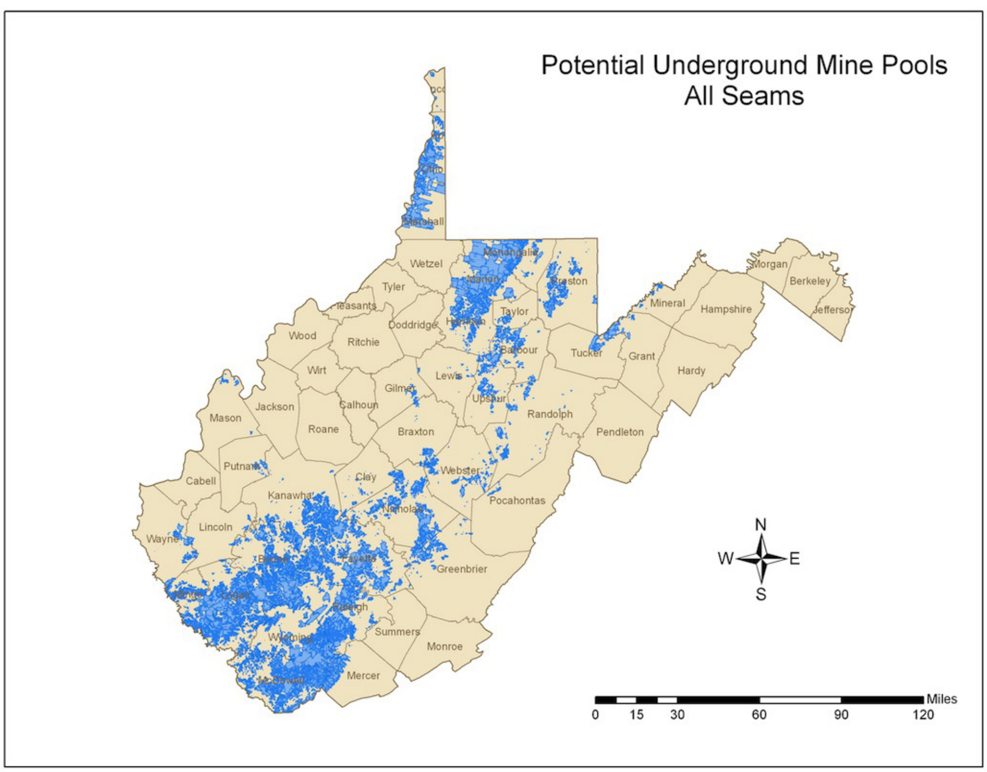

Figure 3. The footprints of all documented underground mines in West Virginia coal beds delineate the areas of potential mine pools in the State (WVGES, 2010a).

GIS analytical tools have been developed for this study to assist in determining the position of each mine with respect to drainage (above, near, or below), the relative amount of potential groundwater flooding (not flooded, partially flooded, or flooded), and direction of groundwater flow. Much of the underground mining in the State occurs above drainage, and the extent of potential mine flooding is more dependent on the orientation of the mine than on the volume of the mined void. Maps and statistics about each mine pool derived from coal bed and mining information available from the WVGES CBMP during the period the mine pool study is conducted are presented in a series of five maps per mine pool in the final report to WVDEP.

The project consists of the following tasks:

- Conducting a regional evaluation of each coal bed to determine which parts of the bed are above major drainage, near major drainage, and below major drainage.
- Calculating the estimated mine pool volume of each coal bed, assuming an average thickness based on WVGES CBMP GIS data and an extraction rate determined by the mining patterns for mines located near and below drainage.
- Developing map templates for the report.
- Preparing maps of each mine pool for the report.

Regional Evaluation

Because this study was ongoing in 2011, the focus of this presentation is the regional evaluation of each coal bed using WVGES CBMP GIS data layers and models. The GIS data layers for each coal bed include underground mine polygons, coal boundaries (croplines), and a structure contour of the elevation of the base of the coal bed (fig. 4). In addition to visual analysis of GIS data layers, models were developed to aid in determining the position of each mine with respect to drainage, the amount of potential groundwater flooding, and direction of groundwater flow.

The Watershed Model, which was used to determine groundwater flow direction, is a standard Environmental Systems Research Institute (Esri) ArcMap™ 10.0 geoprocessing model that uses the Spatial Analyst™ Hydrology toolset to convert the CBMP coal bed elevation raster data into predictive hydrologic flow direction and flow accumulation raster data. From these generated datasets, the model outputs generalized “stream” features that can be used to predict the direction of groundwater movement through mine voids relative to the coal outcrop. This model was run for all coal beds to aid in determining the extent of potential flooding in underground mines. An example of model output for the Sewell coal bed is shown in figure 5.

The Mining Above/Below Drainage Model (MABD), which is a geoprocessing model (a series of standard ArcGIS

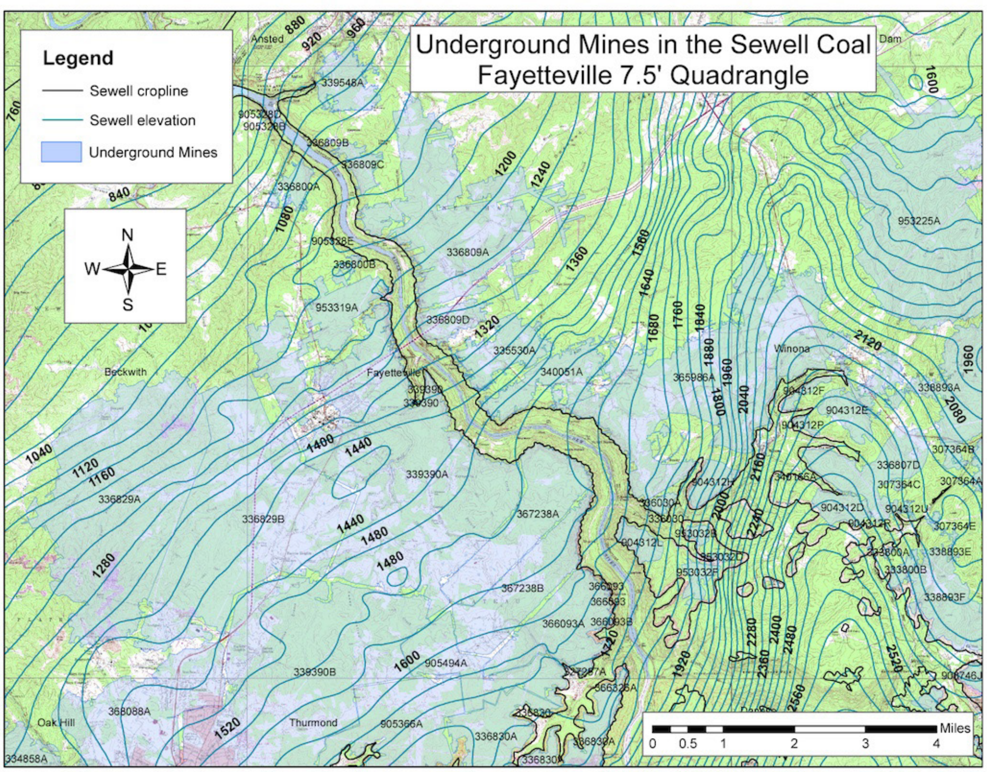

Figure 4. Extent of underground mines in the Sewell coal bed, in the Fayetteville 7.5-minute topographic quadrangle and surrounding area.

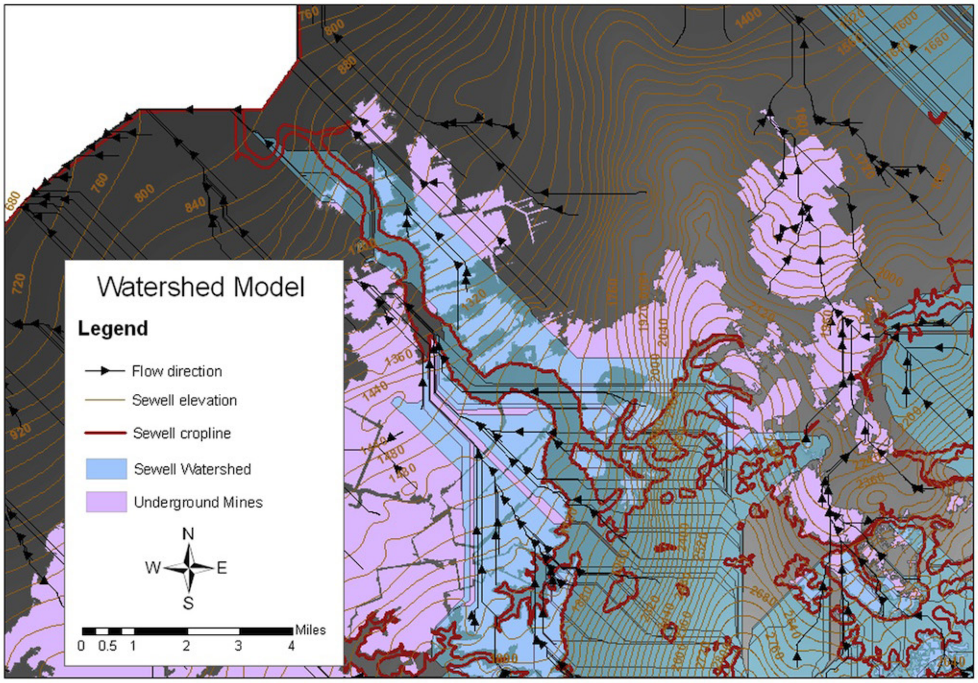

Figure 5. Watershed model output shows predicted direction of groundwater flow through mine voids in the Sewell coal bed. Black arrows show flow direction. The blue watershed zone represents areas contributing to surface-water flow. This model was run for all coal beds having available input data to aid in determining extent of potential flooding in underground mines.

tools executed in a certain order), was developed for this study to determine the position of mines with respect to drainage based on perennial stream elevations. Two versions of the MABD Model, the Major Drainage Elevation Model (MDEM) and the Perennial Drainage Elevation Model (PDEM), were generated by assigning elevations to points selected from the National Hydrography Dataset (NHD) shown on USGS 7.5-minute quadrangle maps and located within hydrologic features. The MDEM selected points located within digitized perennial stream polygons; the PDEM selected points located along digitized perennial stream lines. The resolutions of these digital elevation models (DEMs) were generated to 10 meters to match the CBMP coal bed elevation raster data. The coal elevation DEM was subtracted from the MDEM and the PDEM to indicate regions of the coal bed that lie above and below major drainage; these results were individually overlaid with the mine footprint to obtain the two versions of the final GIS layer of potentially flooded mine areas shown in figures 6 and 7.

The effectiveness of the MDEM and PDEM models was tested by comparing the model output for 472 mines in the Sewell coal bed located in southern West Virginia with the results of the visual structure contour/cropline examination of the same underground mines. The results are shown in table 1. The visual structure contour/cropline examination is the most effective method of identifying drainage position and potential extent of flooding in mines. The MDEM proved ineffective in predicting mine position with respect to drainage and potential extent of mine flooding. The PDEM is a fair predictive tool, but it is most effective in identifying potential flooding below drainage.

The Sewell coal bed was selected to assess the MABD GIS models because it has been extensively mined by underground methods in southern West Virginia (fig. 8). Coal and mining information for the Sewell coal bed, including mine extent polygons, coal cropline, structure contour of the base of this coal, and scanned images of mine maps (WVGES, 2011), were visually examined to establish which areas have adequate data available to determine the position of each mine relative to major drainage (above, near, or below) and to determine the potential for each mine to be partially or completely filled with groundwater. In addition, locations of discharges from a few underground mines in the Sewell coal bed within the New River Gorge near Fayetteville, WV, were verified by fieldwork being conducted for geologic mapping of the Fayetteville 7.5-minute topographic quadrangle map (figs. 9, 10, 11, 12, and 13).

Of the 884 documented mines in this coal bed, 472 are located in areas in which cropline, structure contour, and coal bed elevation raster data are available to provide input to the models. Visual structure contour/cropline examination of underground mines indicates 431 mines are above drainage, 24 are near drainage, and 17 are below drainage. Nineteen of the mines that are near drainage and 250 of the mines above

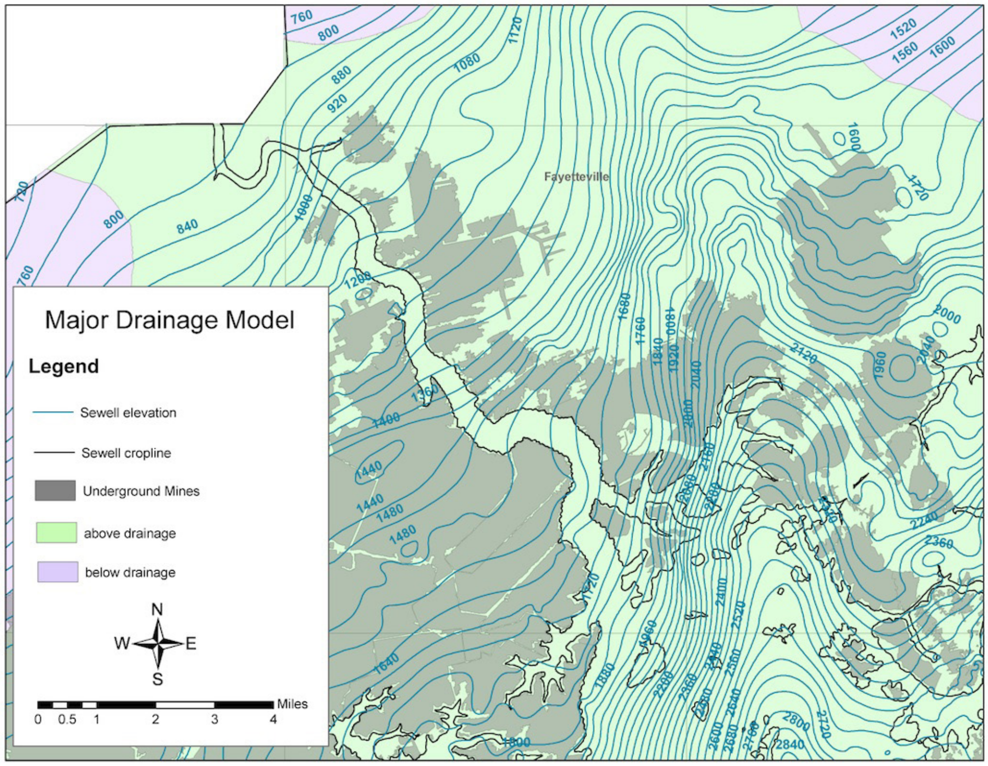

Figure 6. Major Drainage–Mining Above/Below Drainage (MABD) model output shows areas of the Sewell coal bed that lie above and below major drainage. This model, which was developed to determine mine position with respect to drainage based on perennial stream elevations, generated a Major Drainage Elevation Model (MDEM) by assigning elevations to points selected from the National Hydrography Dataset (NHD) shown on the USGS Fayetteville 7.5-minute quadrangle map and are located within digitized perennial stream polygons.

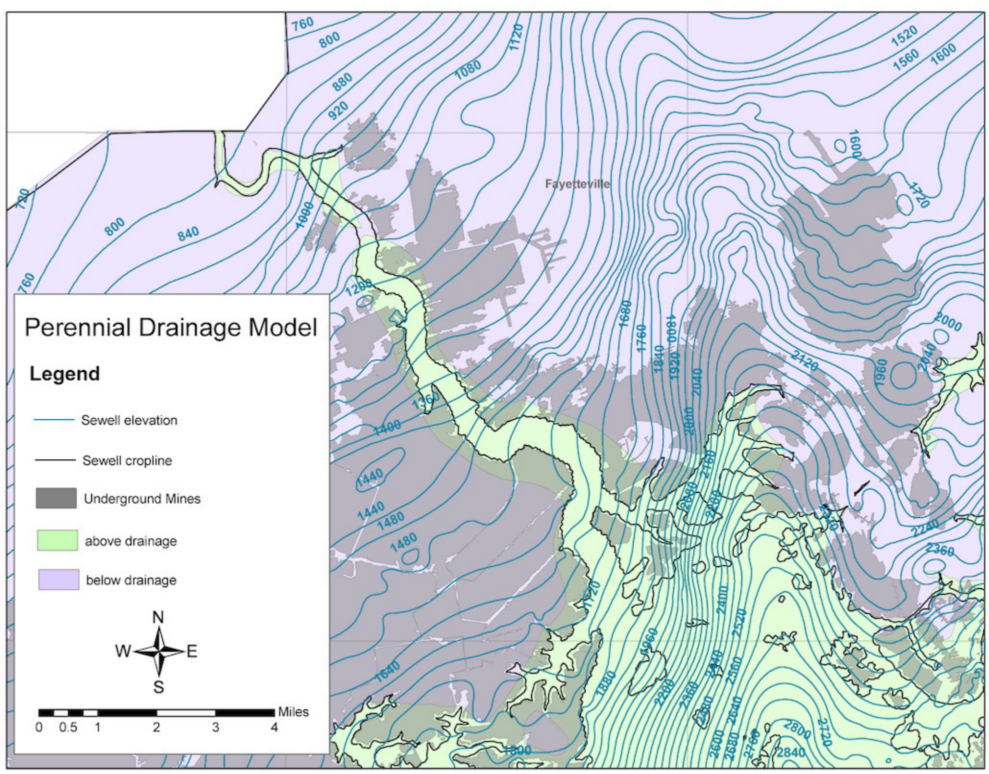

Figure 7. Perennial Drainage–Mining Above/Below Drainage model output shows areas of the Sewell coal bed that lie above and below perennial drainage. This model, which was developed to determine mine position with respect to drainage based on perennial stream elevations, generated a Perennial Drainage Elevation Model (PDEM) by assigning elevations to points selected from the National Hydrography Dataset (NHD) shown on the USGS Fayetteville 7.5-minute quadrangle and located along digitized perennial stream lines

Table 1. Comparison of structure contour/cropline examination to the major and perennial Mining Above/Below Drainage GIS models for determining mine position with respect to drainage and extent of probable groundwater flooding for underground mines in the Sewell coal bed.

Mine position relative to drainage/extent of probable groundwater flooding		METHOD		
		Structure Contour/ Cropline examination	Perennial drainage model	Major drainage model
Mines above drainage	not flooded	181	265	428
	partially flooded	250	118	2
	flooded	0	48	1
Mines near drainage	not flooded	2	0	23
	partially flooded	19	15	1
	flooded	3	9	0
Mines below drainage	not flooded	0	0	12
	partially flooded	0	0	4
	flooded	17	17	1
Total Mines		**472**	**472**	**472**

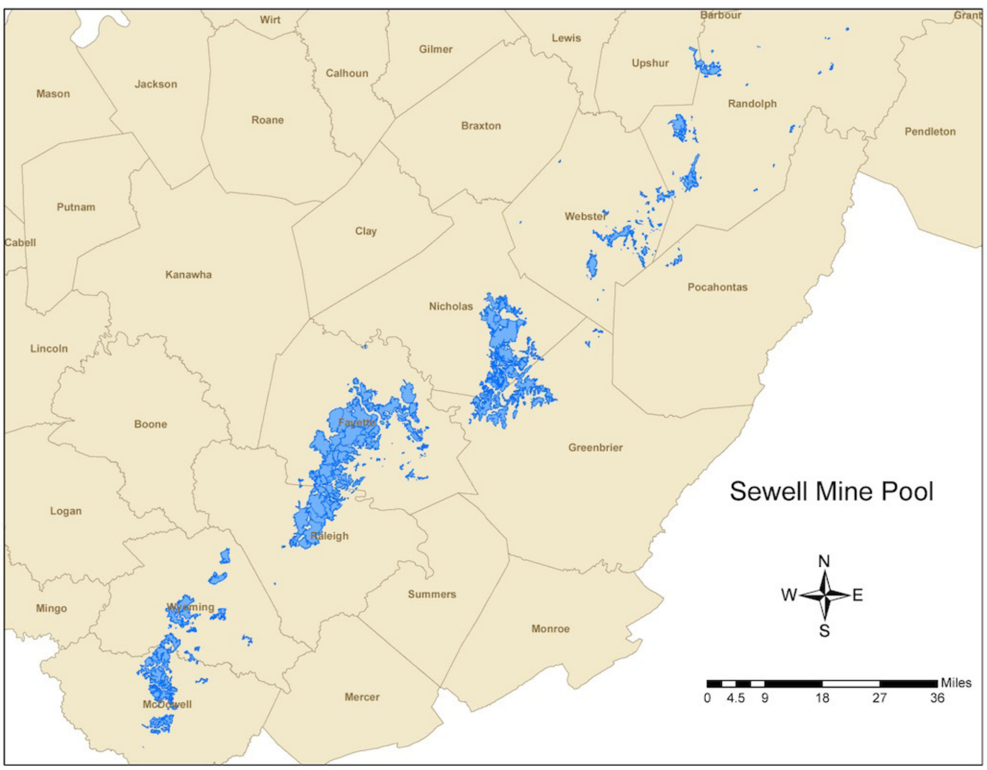

Figure 8. The footprints of all documented underground mines in the Sewell coal bed of the Pennsylvanian New River Formation (WVGES, 2010b).

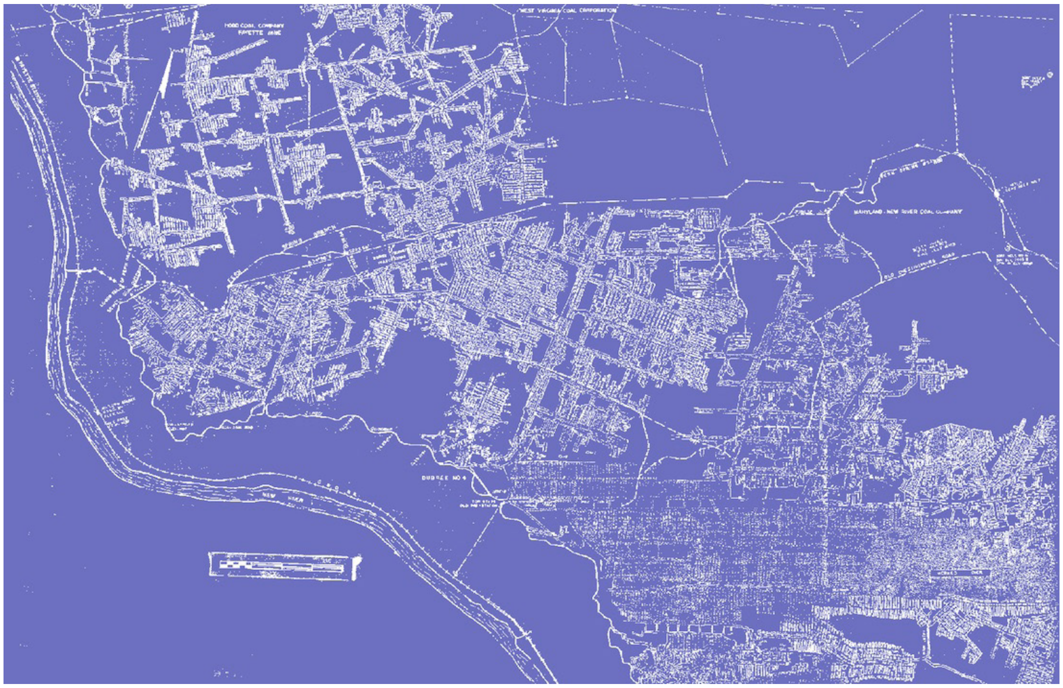

Figure 9. A mine map, Document #340051, shows the locations of Sewell coal mines in the New River Gorge area east of Fayetteville, WV (WVGES, 2011).

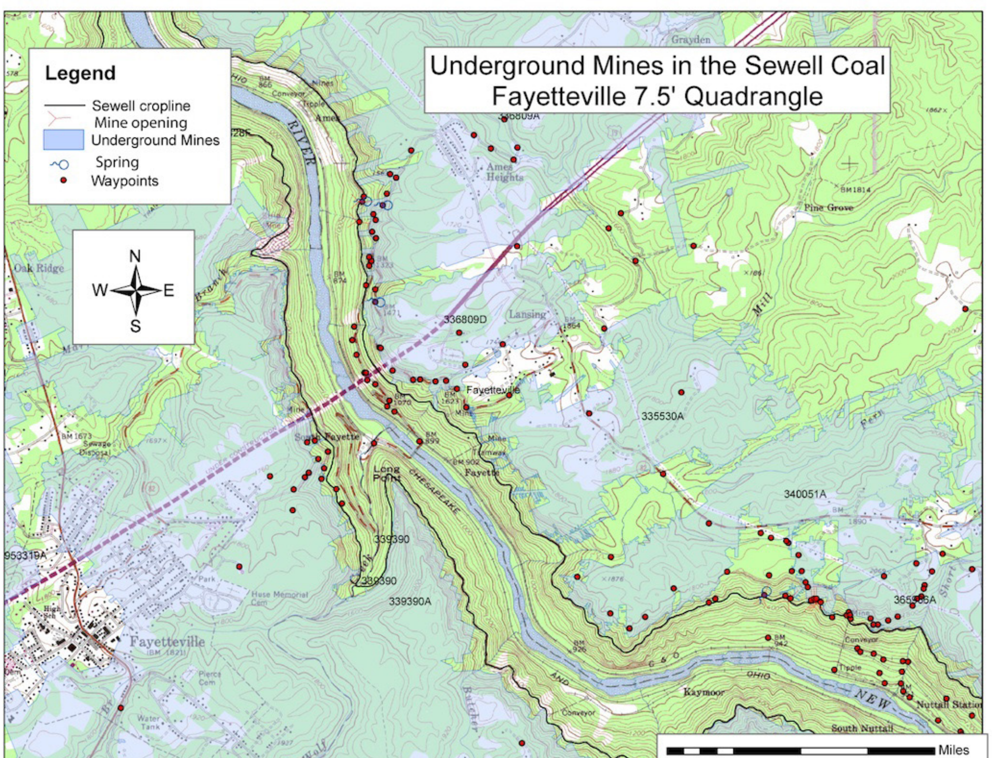

Figure 10. The locations of mine openings and mine water discharges were among waypoints recorded during the process of geologic field mapping.

Figure 11. Mine water discharges from a trough built into an opening in the Ames Mine in the New River Gorge east of Fayetteville, WV (photograph by G.H. McColloch).

Figure 12. Mine water discharges through an earthen seal of an undocumented mine opening in the Sewell coal bed west of the Dubree No. 4 mine near the site of Nuttallburg in the New River Gorge. The location of this photograph is approximately 415 yards west of the location of the photograph in figure 13 (photograph by G.H. McColloch).

Figure 13. At this opening in the Dubree No. 4 mine in the Sewell coal bed near the site of Nuttallburg in the New River Gorge near Fayetteville, WV, no water is detected. The grate over the mine opening provides sufficient access for bats (photograph by G.H. McColloch).

drainage are potentially, partially flooded. Three of the mines near drainage and all 17 mines below drainage are potentially, totally flooded. The potentially completely flooded mines have footprints that range in area from 1.7 to 4,587.4 acres and jointly occupy approximately 33,361 acres. The underground mines located below or near drainage have the greatest potential to provide large quantities of water. The down dip areas of some of the large mines located above drainage may also be potential sources of groundwater.

Acknowledgments

The Mine Pool Atlas project is funded by the U.S. Environmental Protection Agency through the Division of Water and Waste Management of the West Virginia Department of Environmental Protection. Identification of mine drainage sites resulted from field work supported by the U.S. National Park Service to conduct geologic mapping in the New River Gorge National River.

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Geology and History of a 19th and Early 20th Century Industrial Complex: The Nuttall Mine and Nuttallburg, West Virginia

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Introduction

The area between the site of Nuttallburg, West Virginia, and Keeney's Creek in the New River Gorge bounded by the river and the canyon rim at first appears to be a pristine, natural, and largely untouched environment (fig. 1), but in reality the area is an example of the environmental recovery of a late 19th through 20th century industrial complex (fig. 2), owing to proper climatic conditions and benign neglect. At the same time, subtle and sometimes not so subtle evidence of past mining practices and transportation remains and must be taken into account in creating both surficial and bedrock geologic maps and in considering possible future land use. Areas like this are common in West Virginia, given the State's mining and logging heritage.

This project began as we were conducting bedrock geologic mapping on the Fayetteville, WV 7.5-minute quadrangle, in cooperation with the National Park Service in the New River Gorge National River area. Within this quadrangle is the New River Gorge Bridge, the third longest

Figure 1. "Endless Wall" area with study area in center. The term "Endless Wall" originates in the rock climbers community and, although it is formed along a very long cliff line, the term appears to refer to the "endless" number of climbing routes along the cliffs between the New River Gorge Bridge and Keeney's Creek formed by the Upper and Lower Nuttall Sandstones.

Figure 2. Photo of an early 1900s coke oven battery in the New River Gorge obtained from the National Park Service in the mid-1980s. Between the 1870s and the 1980s the Gorge was an industrial area producing both coal and coke using almost exclusively old style "beehive" coke ovens although coke production ended long before mining in the 1980s. The photograph may have been taken in the lower foreground of figure 1, as the topography matches and Nuttallburg had a battery of 46 coke ovens. The New River Gorge had many similar coke oven batteries in the late 1800s and early 1900s.

arch bridge and the fifth highest vehicular bridge in the world. Statistics compiled by the West Virginia Division of Highways indicate the bridge averages 16,200 vehicle crossings per day (Wikipedia, 2012). One local event is Bridge Day, on the third Saturday in October. During this event the bridge is closed to traffic and open for pedestrians, various vendors, base jumpers, and those who wish to rappel from the bridge deck to the bottom of the gorge. This event is preceded by several weeks of preparation, including security sweeps around and under the bridge. We had started working in the bridge area in late 2010, but decided to work elsewhere nearby until after the event. The Nuttall Mine area is between 2 and 3 miles from the bridge, so we focused our efforts there. During the same period, we were taking a surficial geologic mapping course at West Virginia University. One course requirement was to produce a "local surficial map or map project in student area of interest." We were intrigued with the Nuttall Mine, Nuttallburg, and the Keeney's Creek area. We also had access to a new light detection and ranging (LiDAR)-derived digital elevation model (DEM) dataset (U.S. Army Corps of Engineers, 2010), so we decided to propose a joint map in the area. This material will become part of the next version of our New River Gorge field trip guide, but it is also, to an extent, a class project that got out of hand.

We would like to offer particular thanks to J. Steven Kite of West Virginia University for persevering in offering his surficial geologic mapping course when his schedule became very full as he assumed the duties of Chairman of the Department of Geology and Geography. It allowed two geologists who had spent much of their careers trying to look past, and visualize through, surficial deposits to better understand and appreciate these materials. Indeed, in this study area, we found the surficial geology much more fascinating than the bedrock.

Basic Data

In the Appalachian Plateau portion of West Virginia, along with our own field observations, we generally have access to large amounts of surface and subsurface geologic information. West Virginia geology was originally mapped at scale 1:62,500, in the period between around 1900 and 1939. The published data are still useful, but many changes in both geologic theory and technology have occurred in the last 70 years. In addition to the West Virginia Geological Survey's County Report Series, we have access to large numbers of unpublished oil and gas well logs, coal exploration core logs, a few additional logs of cores drilled for scientific purposes, thousands of coal mine maps, and data collected during various field studies subsequent to the county reports. We also have access to many sets of aerial photographs, remotely sensed imagery, and DEMs, including statewide photograph-derived 1/9 arc second DEMs. Along with basic geologic data, the most useful data available for this project have been a collection of very early aerial photographs completed in 1946 (fig. 3) and a newly completed extensive LiDAR dataset collected and processed by the U.S Army Corps of Engineers as part of a flooding study for the Bluestone Lake that provided data along the gorge. The Corps has released LiDAR-derived DEMs, photographs, and point clouds and generously processed much more data than necessary for their original purpose in response to interest from West Virginia's user community (U.S. Army Corps of Engineers, 2010).

The availability of LiDAR-derived and other high resolution DEMs provided the opportunity to experiment with sun angles for hillshading (fig. 4) and computing and classifying slope (fig. 5) to aid in surficial mapping. This approach, coupled with field observations, allowed better interpretations of landforms than just a single hillshade. The hillshading we utilized is the standard methodology available in ArcGIS. Due to the depth and narrowness and meandering nature of the gorge, many slopes require experimentation in terms of sun angle and to bring out surficial features. In the study area (fig. 4) the image is oriented with the north up, and the best sun angles were fairly high from the southwest. Figure 4 afforded the best overall view for our poster. Experimentation with various sun angles in this range brought out both natural and manmade features quite well, but generally left the north-facing slope totally in the dark (fig. 4). Slope classification was also subject to experimentation to see what best portrayed recognizable surficial features. Figure 5 shows what seemed to work best for display with cool colors (mostly blues) for steep slopes and warm colors (mostly reds and yellows) for flat areas and gentle slopes.

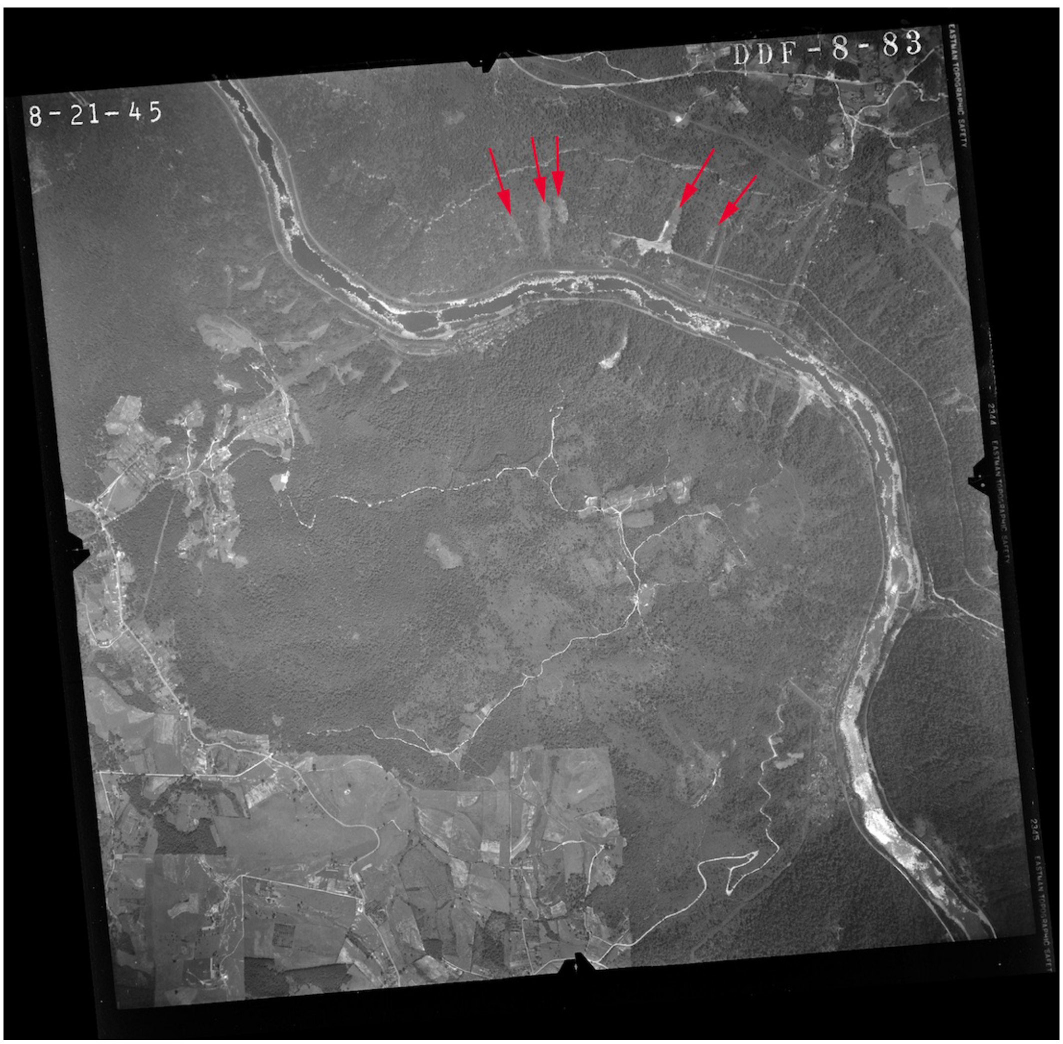

Figure 3. Aerial photograph (1946, by U.S. Department of Agriculture Soil Conservation Service) showing mine dumps (marked by red arrows).

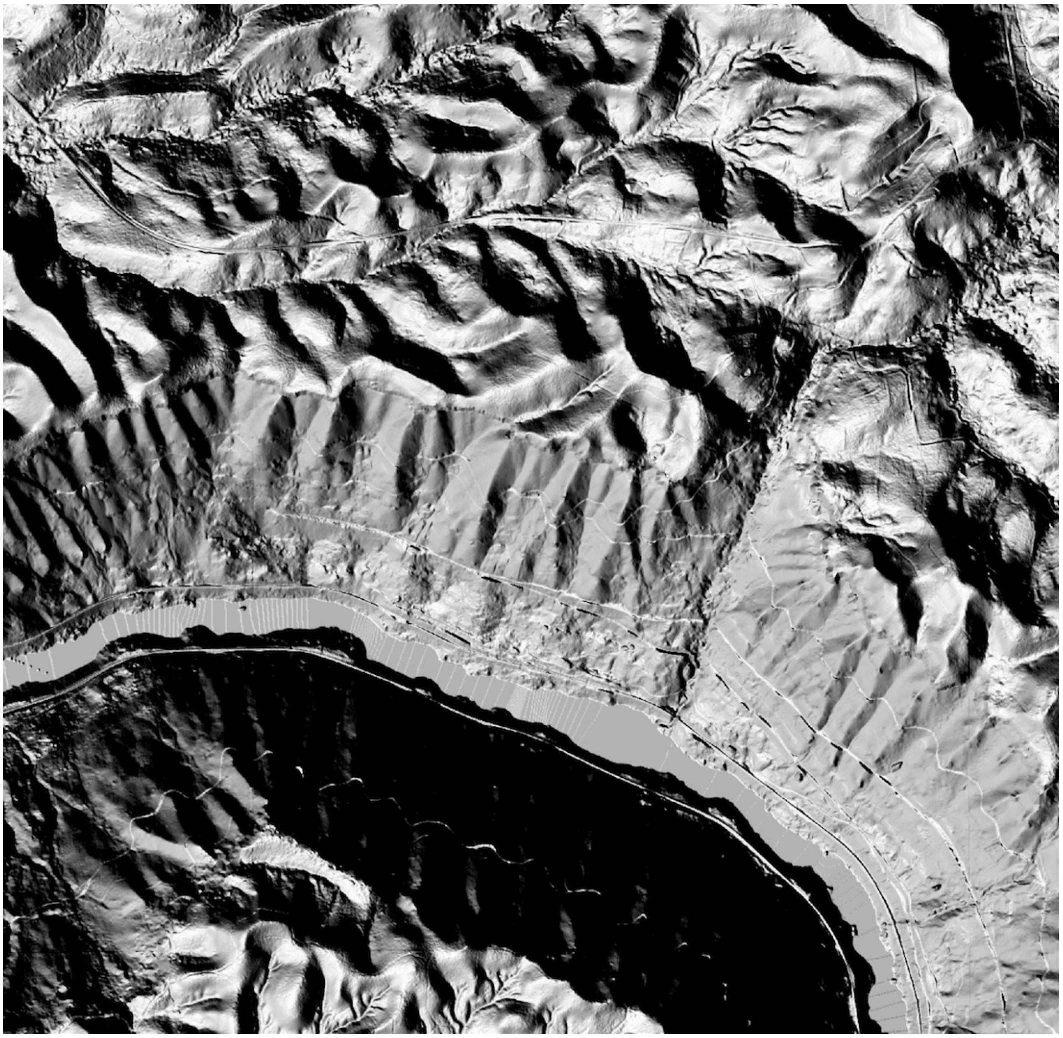

Figure 4. Hillshade of a portion of the study area.

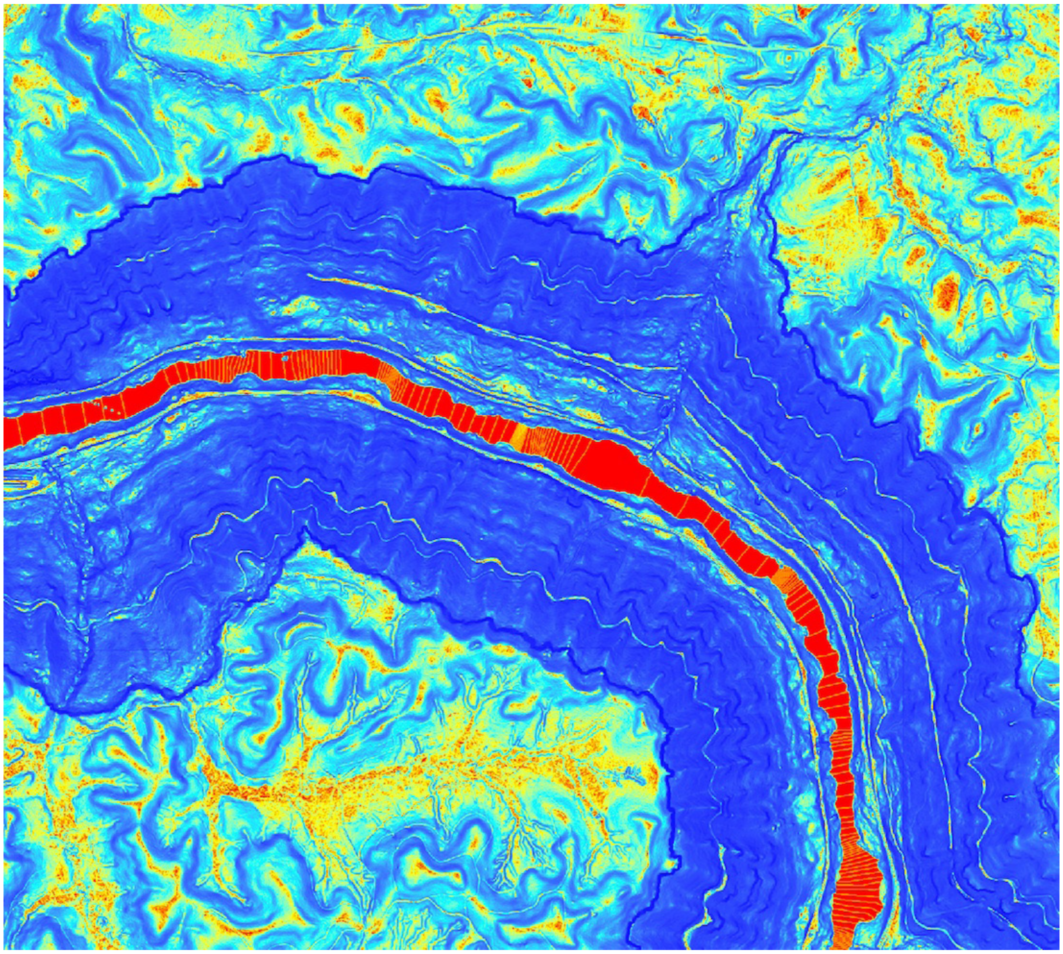

Figure 5. Slopeshade of a portion of the study area (red and yellow areas near horizontal, blue areas near vertical).

Preliminary Bedrock Geology

Preliminary mapping of bedrock geology in the study area also was portrayed in our study (fig. 6). The biggest problem encountered is that deep in the gorge, bedrock exposures are well covered by surficial materials that sometimes bury the bedrock tens of feet deep. Good bedrock exposures are limited to railroad cuts, cliffs high in the walls of the gorge, and occasional exposures along the few permanent roads. Contacts frequently have to be projected for several miles based on structure contours and topography. We have high-quality data, but these projections are sometimes necessarily distant enough to be somewhat unsettling. One gap in bedrock data generally occurs in the relatively shallow subsurface between the bottom of available core logs and the depths in oil and gas well geophysical logs where data collection begins; this is the case in the study area. Our projections indicate that the unnamed sandstone in the upper Bluestone Formation exposed around Thurmond might occur in the banks of the New River in the eastern part of the study area, but so far we have not been able to find an indisputable bedrock exposure. It is likely that the exposure is buried by surficial deposits or railroad fill. This unit was projected downriver, based on good exposures far upstream and across the river near the Park Service's Cunard river access facility.

Impact of Human History on Surficial Geology

The history of the Nuttall Mine, which is typical of West Virginia's first generation of large metallurgical coal mines, was relatively long, included several owner-operators, and involved the evolution of mining technology from hand loading with animal haulage to mechanized mining. Details of this history are well documented in Library of Congress documents by Maddex (1991), but a few important historical points bear repeating in order to better understand the three surficial geologic maps that we produced (figs. 7, 8, and 9). At this location, mine site preparation began in 1870, and mining began in February 1873, following completion of the main line of the Chesapeake & Ohio (C&O) Railroad in the gorge. Completion of the railroad allowed the delivery of heavy equipment and shipment of coal and coke to market. The mine, the conveyor route, most roads, and the company town of Nuttallburg were built in the gorge between 1870 and 1873 (Maddex, 1991). Development modified the area of the slope above the north bank of the New River to raise the land elevation enough to prevent the tracks from flooding. This railroad construction, of course, heavily affected the landscape in the area near the tracks. Two natural features directly

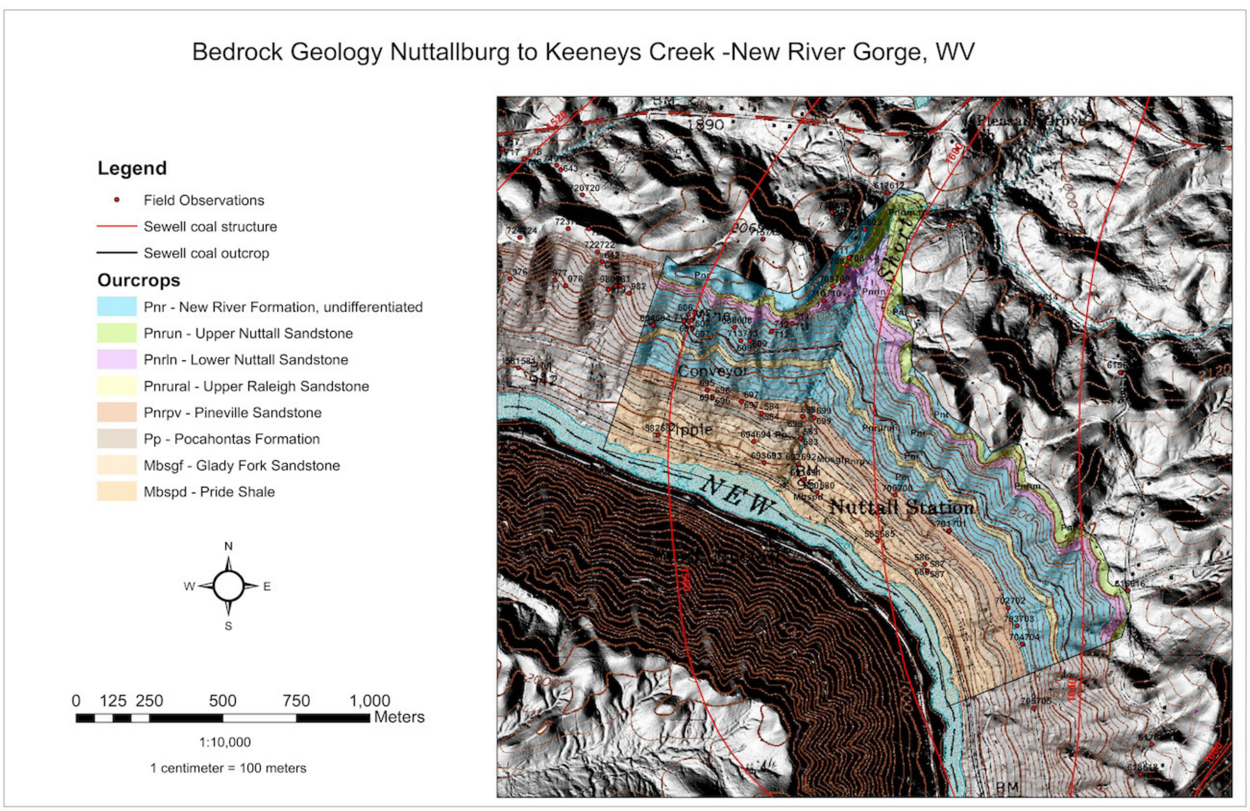

Figure 6. Preliminary bedrock geology, from Nuttallburg to Keeney's Creek – New River Gorge, West Virginia.

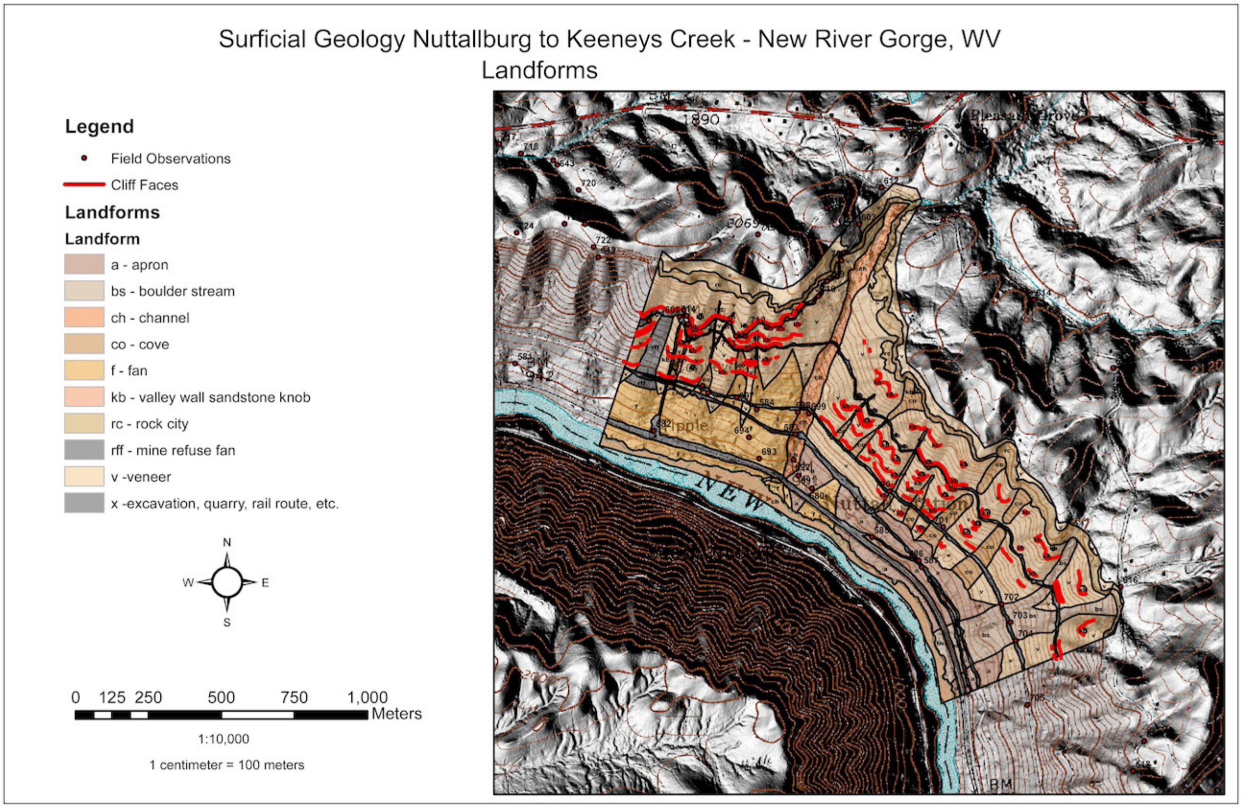

Figure 7. Surficial geology: Landforms.

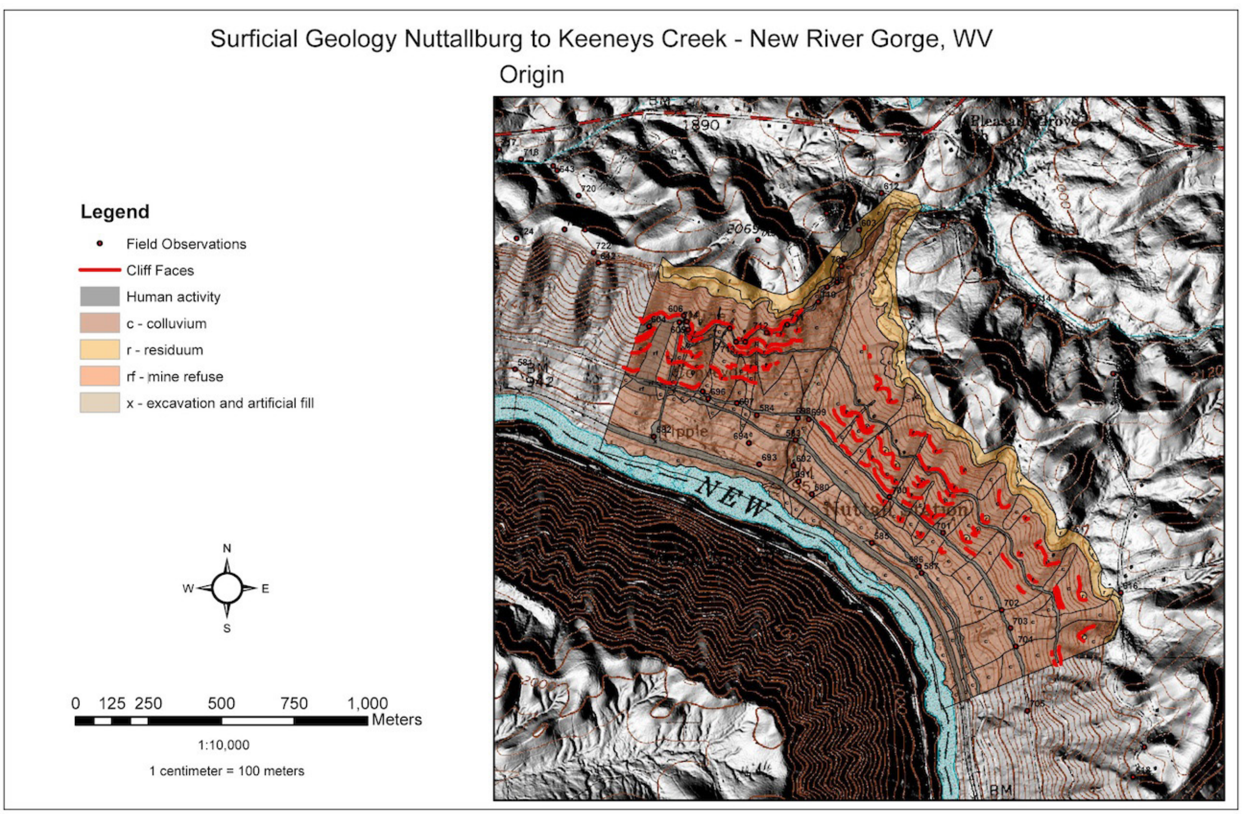

Figure 8. Surficial geology: Origin.

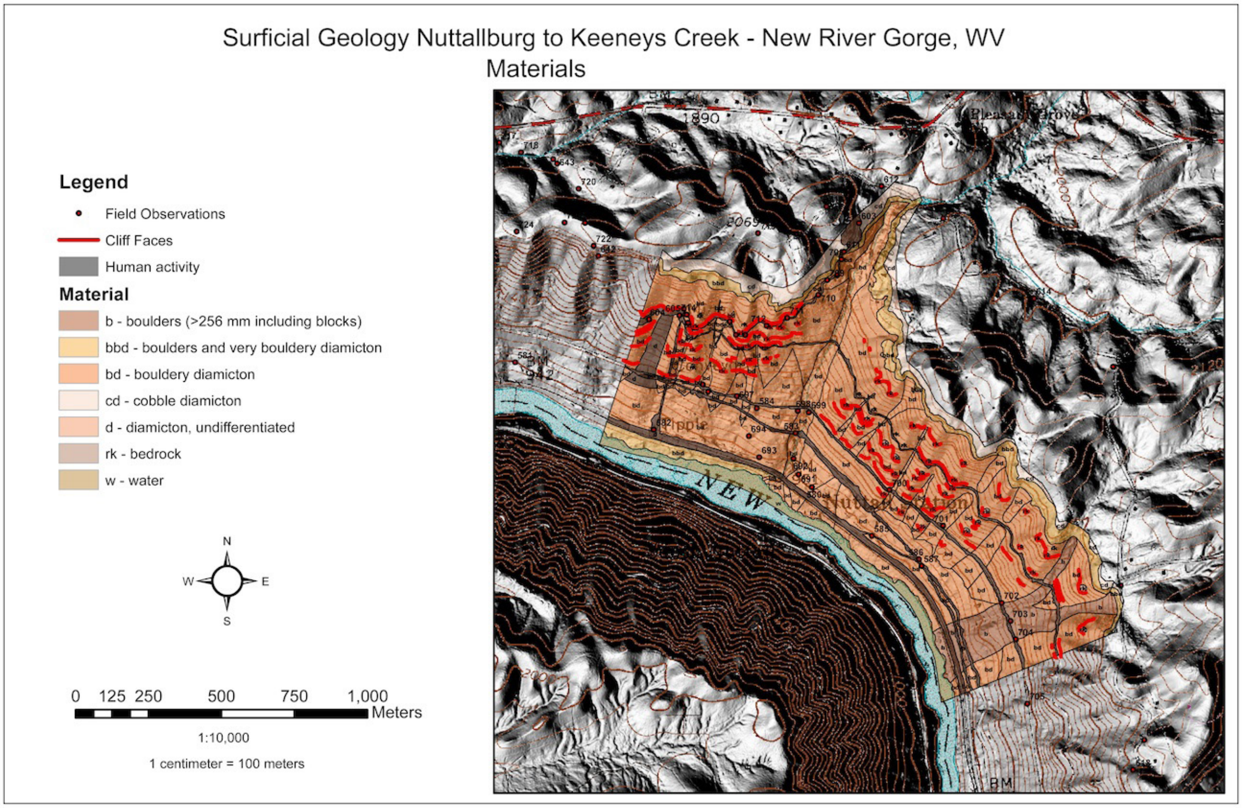

Figure 9. Surficial geology: Materials.

affected were the nested alluvial fans located at the mouth of Short Creek in the middle of the study area. The outlines of the original fan can be seen in a shaded relief surface map constructed from LiDAR data. Within this feature, a smaller fan formed when the flow of Short Creek was constricted by the bridge that carries the main C&O Railroad across the creek (fig. 7).

The next big construction project in the area was development of the C&O Keeney's Creek Branch to aid in development of coal resources on Keeney's Creek and in the Lookout, WV, area. Excavations and the remaining bridges for this branch are evident across the lower part of the study area. The lower part of this railroad grade, including bridge improvements, has recently been converted to a mountain bike trail by the National Park Service. The first phase, from Nuttall Station to Rothwell, was completed in 1893 and was approximately 5 miles long (Maddex, 1991). The second phase extended the line 2 miles, to Lookout, WV, in 1903 (Maddex, 1991). This construction appears to have substantially altered the topography and surficial deposits along its route, particularly in the study area. One of the most obvious changes across Short Creek on the lower portion of the slope is the fan deposits west of Short Creek, which are in contrast to the apron with one small remaining fan east of the creek. We suspect the reason for this difference is that much of the material in any eastern fans was either incorporated into the C&O Keeney's Creek Branch, obscured, or further modified by more than a century of erosion influenced by the presence of the railroad grade.

The other geologically important features of human origin found in the study area that are typically not well documented are the mine dumps. One of these has the superficial appearance of a rock glacier, but such a landform is unlikely to be found this far south. We suspected that it might be a mine dump given its location immediately below the Nuttall Mine and its appearance, along with at least five or six other mine dumps (fig. 3) shown on a 1945–46 aerial photography (U.S. Department of Agriculture Soil Conservation Service, 1946), was confirmed by a traverse we conducted along the railroad route to examine all of the mine dumps. It appears that the practice involved dumping mine waste in coves on the slope immediately below a mine railroad that ran from the mine to the ventilation fan house (Maddex, 1991) and then extending roughly along the outcrop of the Sewell coal west of the mine site. The first feature we noted in the mapping area immediately below the mine is probably the oldest as it was initially the easiest place to dump mine waste. We have examined the photographs, mine maps, and various visualizations of the area derived from recently released LiDAR data obtained by the Corps of Engineers (U.S. Army Corps of Engineers, 2010) and have found no clear evidence that substantial mine dumps occur east of the Nuttall Mine. Apparently mine railroad tracks along a bench that approximately follows the outcrop of the Sewell coal east of the mine were only used as storage for empty underground mine haulage cars (Maddex, 1991), which is a reasonable assumption given the danger this would have posed to the C&O Railroad Keeney's Creek Branch line. It also appears that the first dump immediately below the mine might have negatively affected initial construction of the large switchback on this branch line (fig. 3).

We had little time to fully explore some of the harder to reach surficial polygons because our real role in the New River Gorge National River (NERI) mapping project was to produce bedrock geologic maps. One peculiar area is adjacent to and east of the conveyor route. It is a small cove that appears anomalous, and it is possibly an artifact of the conveyor operation or construction.

Unique Natural Features

An unusual landform commonly appears in the New River Gorge, which we have not found noted in the literature; these are rocky knobs that occur on the valley walls on ridges between coves where resistant sandstones crop out (fig. 10). We have called these simply valley wall sandstone knobs, but would welcome a better term.

Figure 10. Small valley wall sandstone knob along the Nuttall Mine access road.

Figure 11. Photograph of boulder stream, taken from trail in former Keeney's Creek Branch railroad bed.

Another apparently natural feature that we observed in the field is a forking boulder stream in the southeastern part of the study area (fig. 11). We do not understand the origin of this feature, but it occurs in the area where the clean, hard Lower Nuttall Sandstone begins to be well exposed above the walls of the gorge on the steeply dipping (maximum ~5 degrees) western limb of the Mann Mountain Anticline. We have encountered similar features in subsequent field work.

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Global Data Access for Mining (GDAm) Showcase—A Collaboration Tool Using Your Geologic Map Data

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Introduction

Global Data Access for Mining (GDAm) is a showcase geographic information system (GIS) Web application collaboration tool created by Esri's Energy and Mining Industry Team. The application highlights using framework Esri GIS technology (fig. 1) to create a powerful tool for browsing, searching, and discovering data and seamlessly launching the data into a variety of workflows to access, analyze, and share data (fig. 2).

GDAm was created using Microsoft SharePoint 2010 and the new ArcGIS Map Web Parts and introduces the overall functionality of Esri's framework GIS system technology implemented into a simple, rich Internet application (fig. 3). GDAm takes advantage of the power of ArcGIS Desktop and Server for authoring and serving a simulated mining company's data combined with the collaboration tools of Microsoft SharePoint highlighting the independence of company data and applications using the power of services-oriented architecture (SOA).

Four sample mining industry workflows are included in the showcase, including Data Discovery and Access, Land Management, Geoscience, and Health & Safety. In all these examples, geologic map data can be easily and quickly added to add intelligent decision making (fig. 4). Of special note when serving your geologic maps is the need to secure your online map services (fig. 5). Special attention should be given to granting "cross domain" access to your map services by using the appropriate security settings (fig. 6).

Demonstration

This was both an oral presentation and a live digital demonstration of the application.

Acknowledgments

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ArcGIS10, Esri, 380 New York St., Redlands, CA 92373-8100 U.S.A., (909) 793-2853, *http://www.esri.com/*.

Esri Cross Domain Help, *http://resources.esri.com/help/9.3/ArcGISServer/apis/Flex/help/Default_Left.htm#CSHID=references%2Fusing_crossdomain_xml.htm*.

ADOBE Cross Domain Help, *http://livedocs.adobe.com/flex/3/html/help.html?content=security2_04.html#139879*.

MICROSOFT Client Access Policy Help, *http://msdn.microsoft.com/en-us/library/cc197955(VS.95).aspx*.

Figure 1. Esri's ArcGIS10. A complete GIS system for easy, powerful and everywhere GIS.

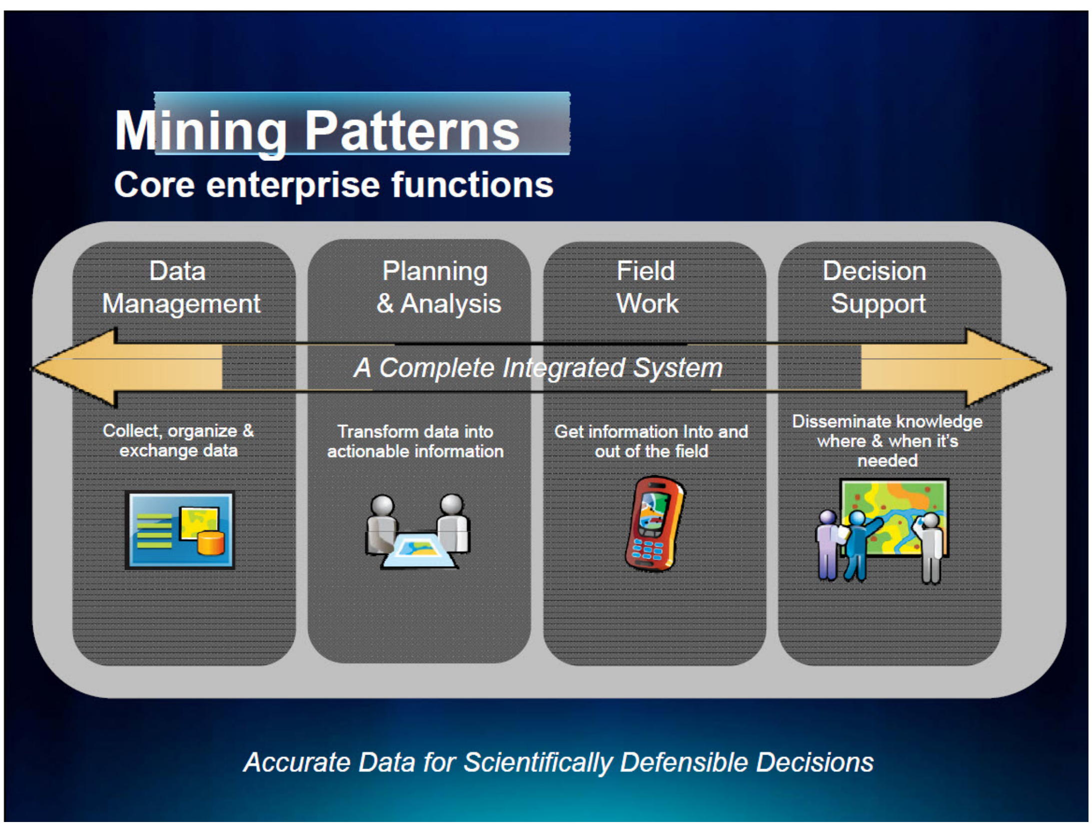

Figure 2. Esri's core enterprise GIS functions of data management, analysis, mobile, and decision support to enable accurate data for scientifically defensible decisions.

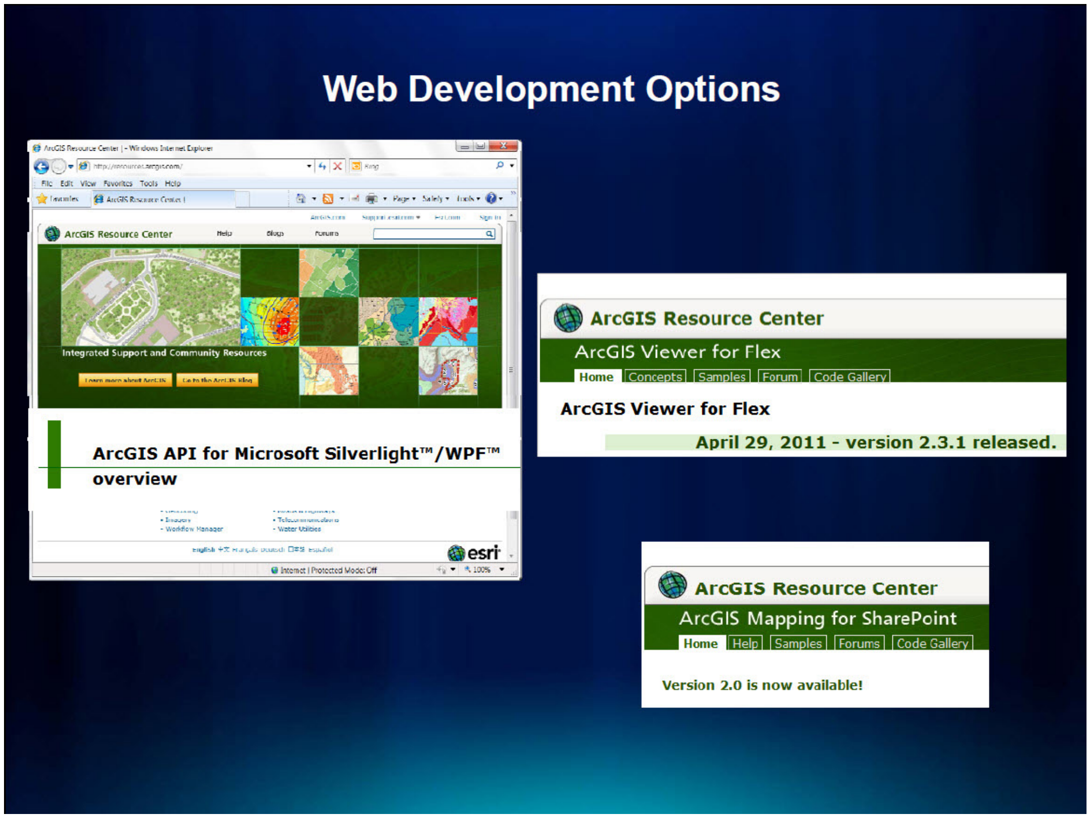

Figure 3. Web development options from Esri (*http://resources.esri.com*).

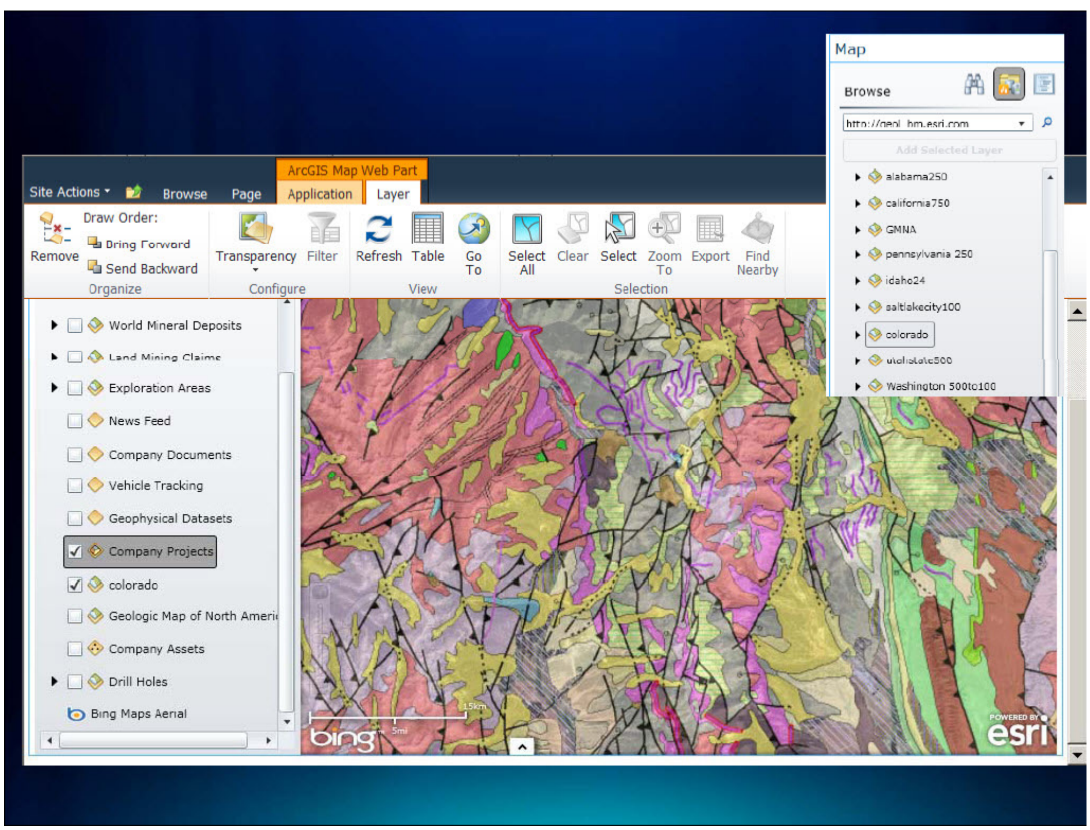

Figure 4. An example of Global Data Access for Mining (GDAm) SharePoint Web application with a geologic map combined with other data layers of interest to mining users.

Figure 5. Examples of Web application server map service security for State and Federal agencies.

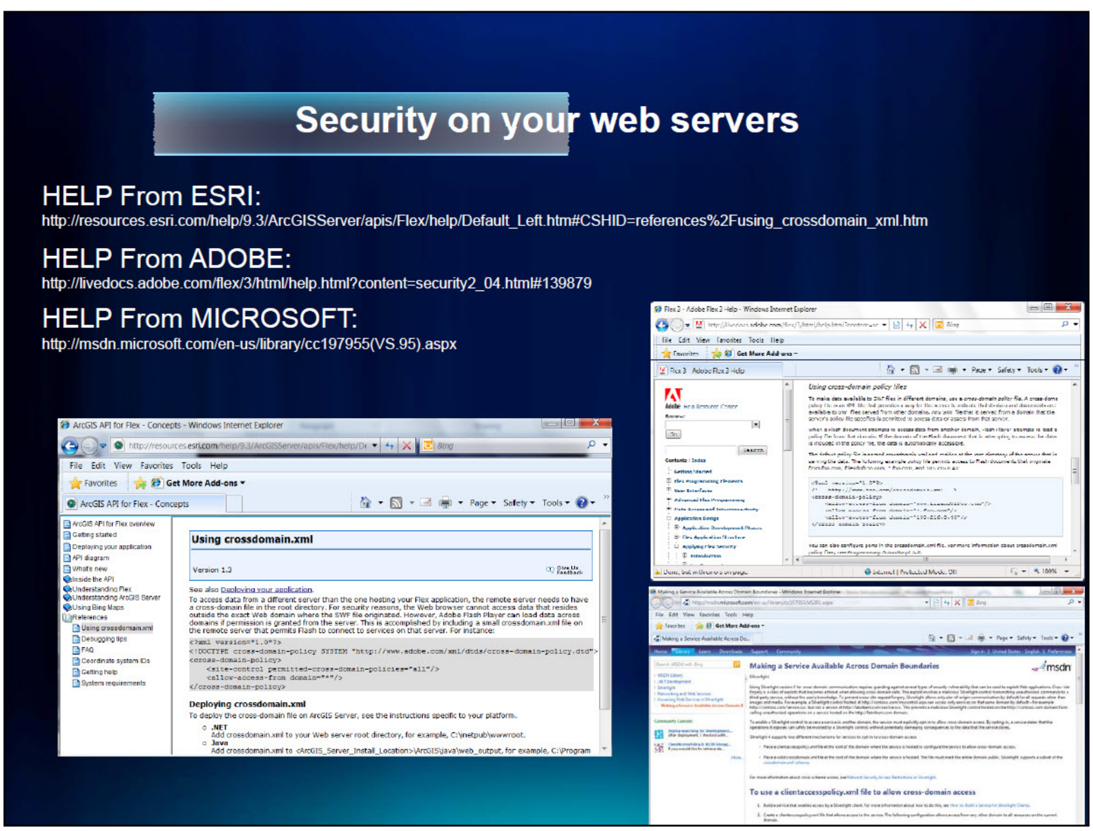

Figure 6. List of Web sites with resources for implementing cross-domain and client access policies from Adobe, Microsoft, and Esri.

Placita 7 ½-inch Quad, Pitkin County, Colorado—3D Geology Map Using Esri ArcGIS10

By Willy Lynch

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Fax: (303) 449-8830
email: *wlynch@esri.com*

Introduction

The Placita 7 ½-inch quadrangle covers the southern portion of the Carbondale, Colorado, coal mining area near Redstone, Pitkin County, Colorado. In 2010, I presented an example of data capture and conversion into Esri Geodatabase using new 2D and 3D capabilities of Esri's ArcGIS10. As an example of a complete 3D geologic map, the draped 2D data from the original maps has been extruded into a fully functional 3D geologic model.

Demonstration

This poster was both a paper printed product and a live digital demonstration of the data.

Acknowledgments

The author thanks Geoff Wade and Danny Spillmann of ESRI for their ongoing support of geology and natural resource industry activities at Esri, and Dave Soller (U.S. Geological Survey) for all his tireless work with the Digital Mapping Techniques (DMT) program.

References

ArcGIS10, Esri, 380 New York St., Redlands, CA 92373-8100 U.S.A., (909) 793-2853, *http://www.esri.com/*.

Kent, B.H., and Arndt, H.H., 1980, Geology of the Carbondale coal mining area, Garfield and Pitkin Counties, Colorado: U.S. Geological Survey Open-File Report OF–80–709, scale 1:24,000.

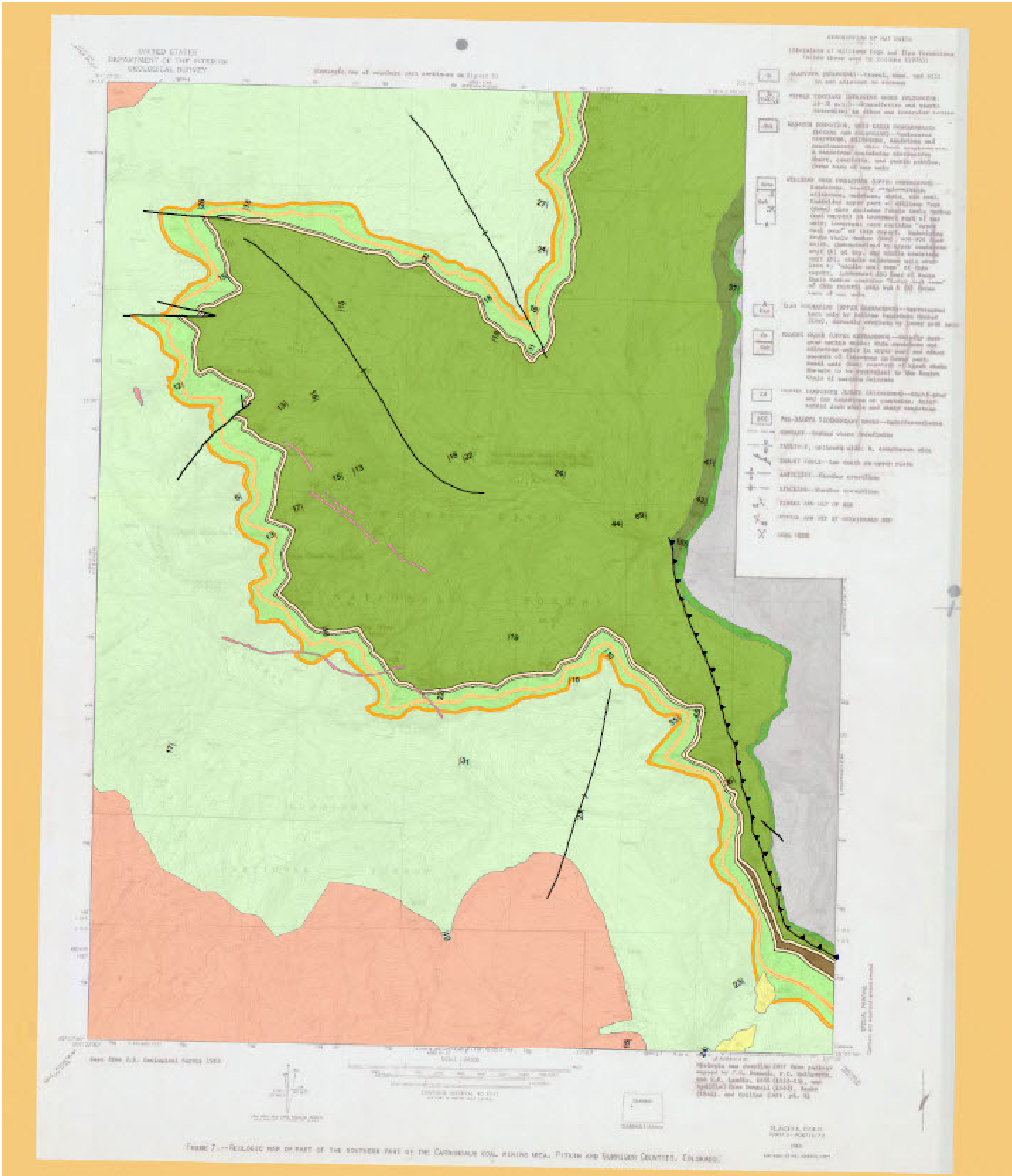

Figure 1. Placita 7 ½-inch geologic quadrangle showing the source data from U.S. Geological Survey Open-File Report OF–80–709 of the Carbondale Coal Mining area (Kent and Arndt, 1980) used for creation of the new 3D geologic quadrangle map.

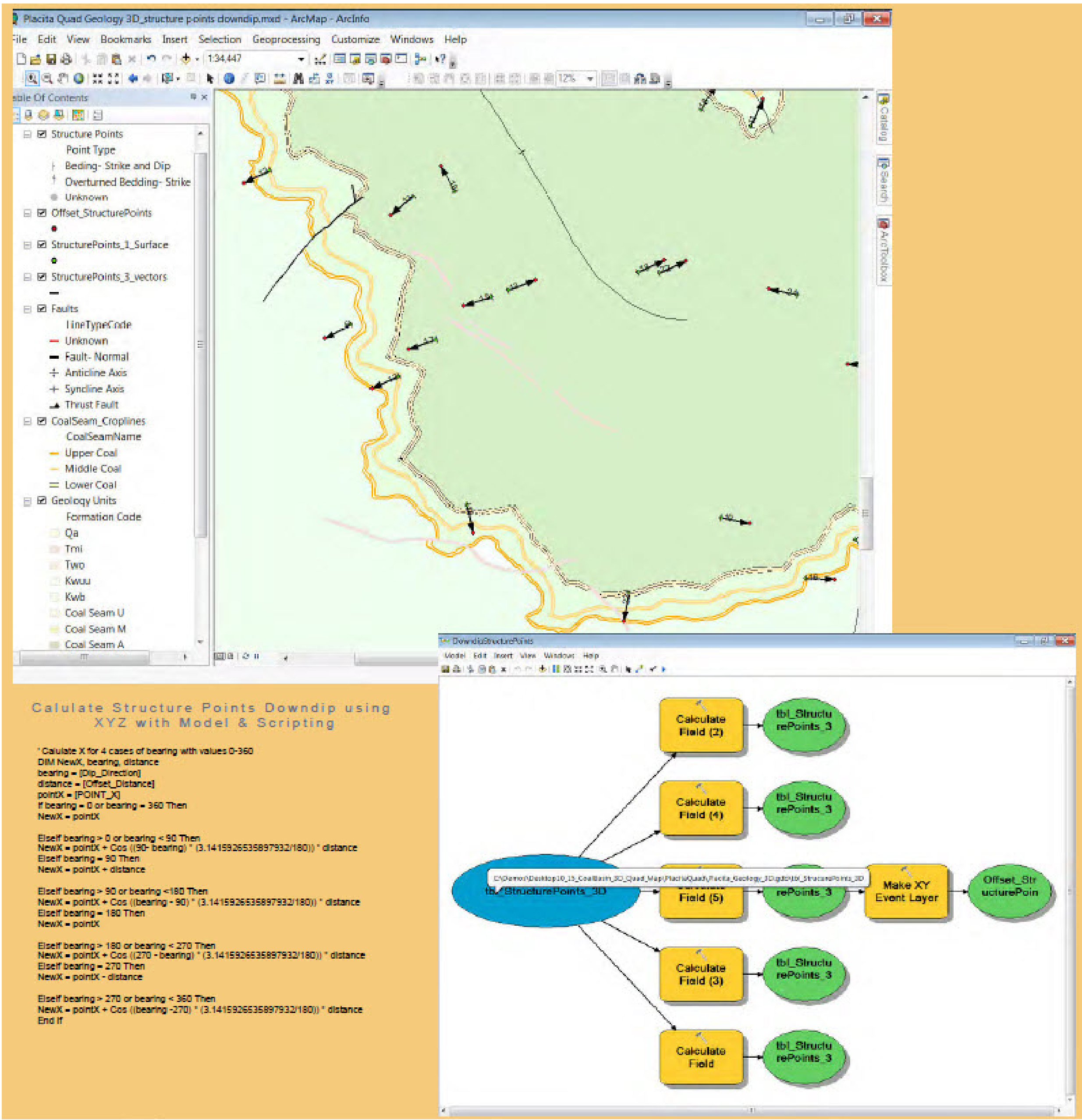

Figure 2. Esri ArcGIS10 ArcMap 2D GIS map showing the Placita 7 ½-inch geologic quadrangle with 2D geologic point, line, and polygon features and conversion tools used to create 3D features.

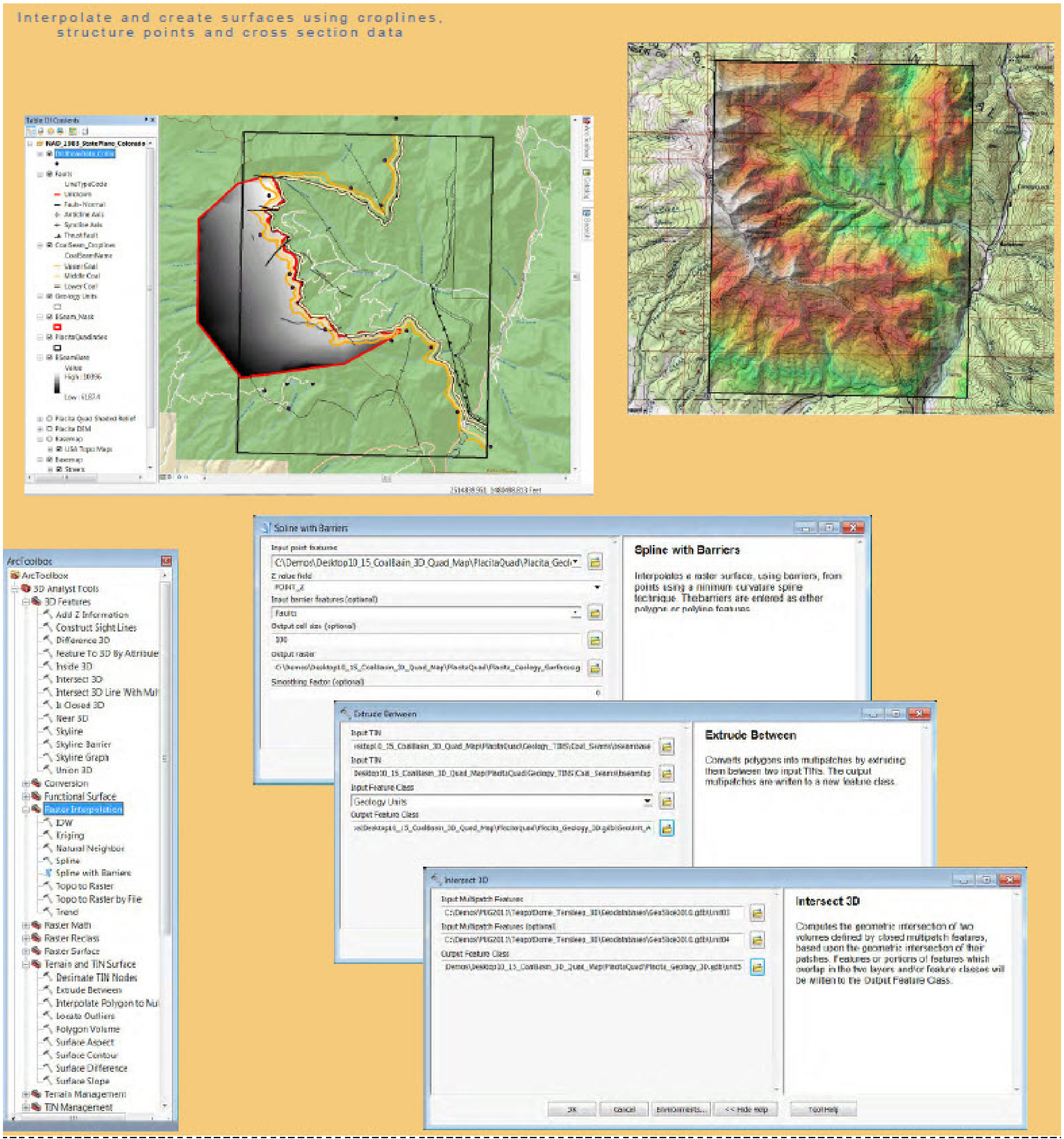

Figure 3. ArcGIS10 3D tools used to interpolate 3D surfaces, extrude 3D multipatch features, and intersect 3D geologic units.

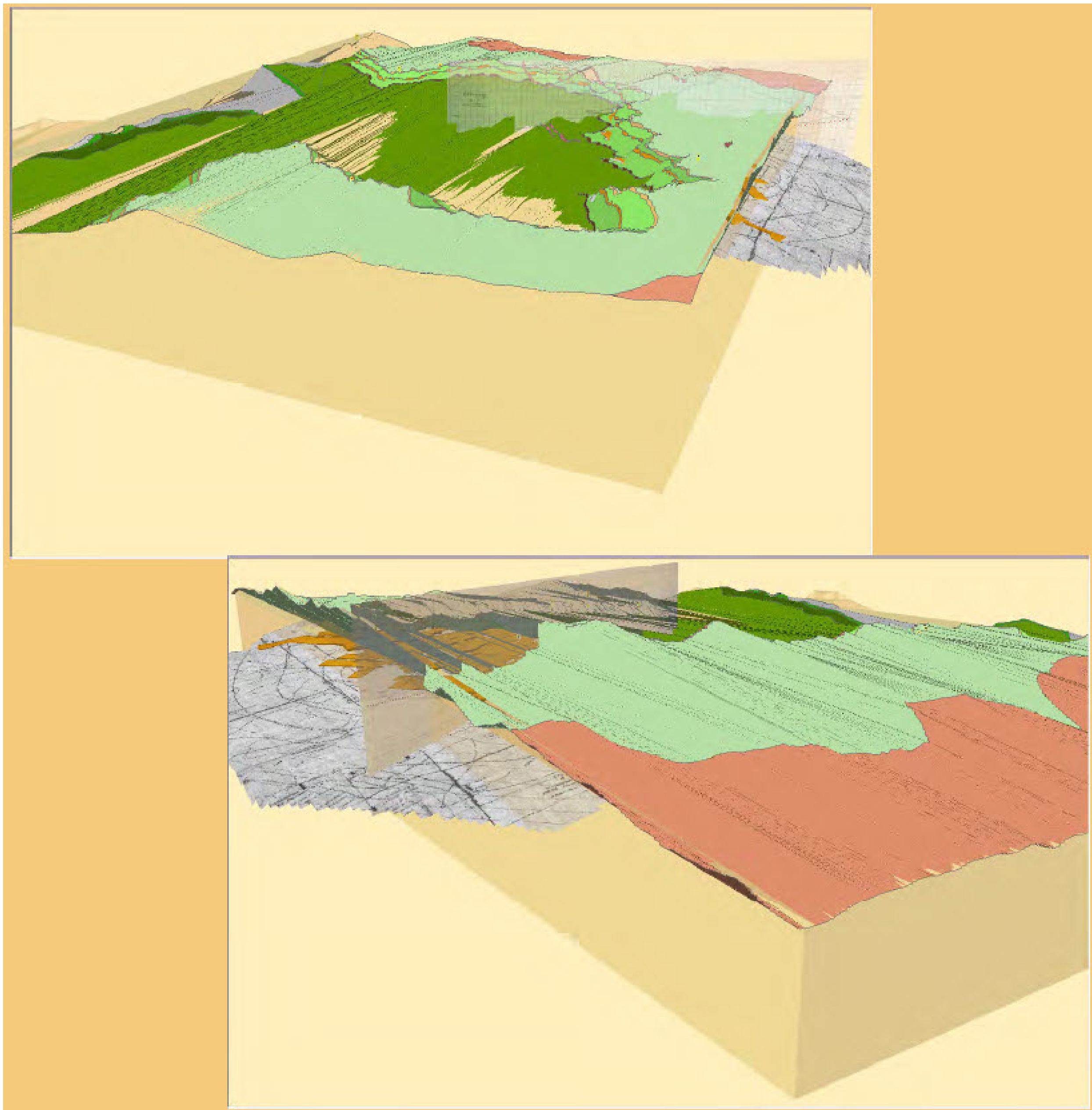

Figure 4. Esri ArcGIS10 ArcScene 3D GIS views of the Placita 7 ½-inch geologic quadrangle as 3D perspectives of geologic block model showing surface geology draped on topography and subsurface 3D multipatch features.

The Alaska State Map: Creation of Draft Map Unit Descriptions Through the Map Database

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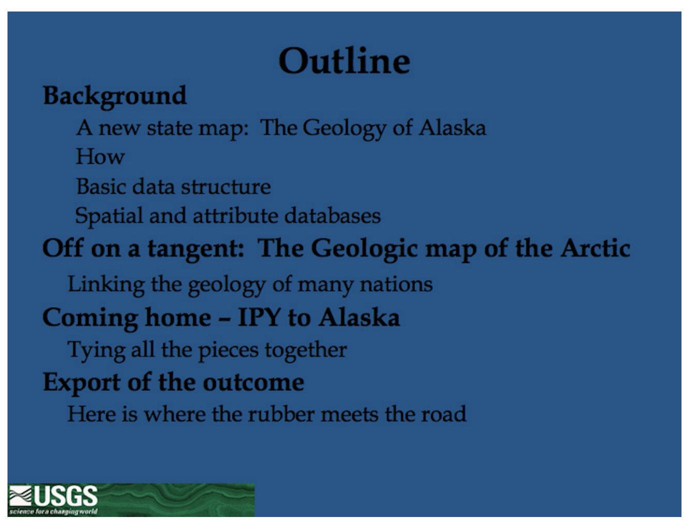
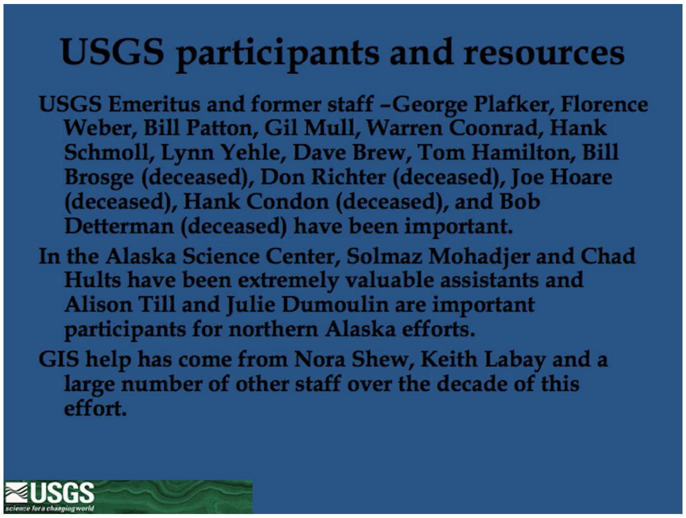
The U.S. Geological Survey (USGS) Mineral Resources Program has engaged in an effort to produce a new geologic map of Alaska to replace the existing, out of date map (Beikman, 1980). Initially part of an effort to prepare for a national mineral resource assessment, creation of this map was recognized to have much wider use and value. The map compilation effort is based on capturing and digitally integrating original source maps at varying scales to produce a spatial database and related attribute databases suitable for use at 1:500,000 scale. However, data typically are captured at 1:250,000 scale and in a number of instances at 1:63,360 scale. To date, nearly 1,000 sources and more than 16,000 individual map unit descriptions have been incorporated.

As part of this ongoing effort to develop a new geologic map, an extensive relational database of geologic information has been developed. This relational database contains abstracted unit descriptions from hundreds of source maps, all linked through a unifying code, that we add, called "NSACLASS." Also linked through this unifying code are lithologic characteristics of the map unit, a rudimentary assignment to a geologic or tectonic setting, and a maximum and minimum age assignment for the linked geologic units. In the process of developing the State map, a series of regional maps have been published, and full unit descriptions from these maps also are incorporated in the database and linked through the unifying code.

Finally, through a related effort to contribute to a Circum-Polar geologic map, a rapid method to characterize geologic units was developed and served to help define links between geologic units across the Circum-Polar region. [The Circum-Polar map was released at the International Union of Geological Sciences (IUGS) meeting in Oslo, Norway, in 2008.] When the time came to define and write unit descriptions for the new Alaska map, a method to reduce the more than 16,000 source map geologic units and more than 1,300 units linked through NSACLASS to a manageable number for the State map was needed. At the same time, we wondered if the database we built could be used to help write the unit descriptions. This paper describes the experiment we attempted. The format for this paper is essentially the text, verbatim from the oral presentation, provided beneath the relevant Powerpoint slide.



Here (above) is the outline of this presentation.



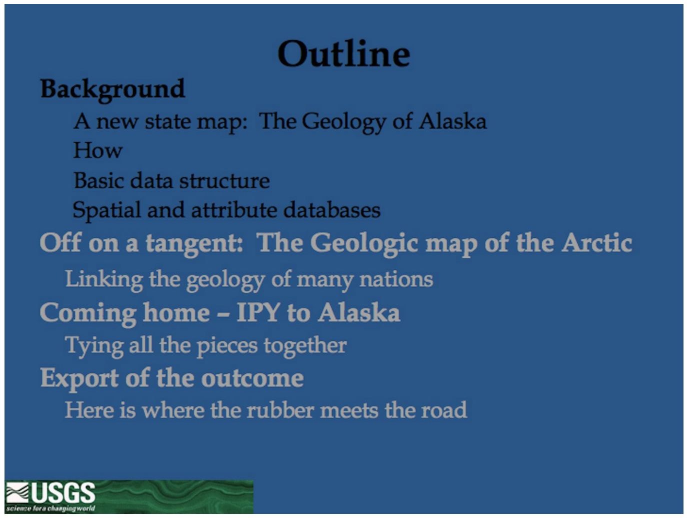
The project would have had little chance of success without the participation of a large number of USGS Emeritus scientists, representing hundreds of years of experience in Alaskan geology. The emeritus included Don Richter for the Wrangell-Saint Elias National Park and Preserve map, Florence Weber for Interior Alaska, Bill Patton for areas throughout western Alaska and Saint Lawrence Island, George Plafker in the eastern Gulf of Alaska region, Warren Coonrad in southwest Alaska, Hank Schmoll and Lynn Yehle in south central Alaska, Dave Brew in southeast Alaska, Tom Hamilton in northern Alaska, and through their notes and maps, Joe Hoare, Bob Detterman, and Bill Brosgé. Special thanks also go to Gil Mull, formerly of the Alaska Division of Geological and Geophysical Surveys (DGGS) and the USGS. In the USGS Alaska Science Center, Solmaz Mohadjer and Chad Hults have been extremely valuable assistants, and Alison Till and Julie Dumoulin are important contributors to the geology of northern Alaska. Geographic information system (GIS) help has come from Nora Shew, Keith Labay, and a large number of other staff over the decade of this effort.

Other collaborators and supporters have included the Alaska Division of Oil and Gas (DOG), which twice has provided financial support for development of our first regional map, covering central Alaska, and for the Cook Inlet regional map of south central Alaska. The Alaska Division of Geological and Geophysical Surveys (DGGS) has contributed detailed mapping in many areas around the State. In addition, the DGGS Web site provides scanned images of all available DGGS and USGS publications about Alaska, a priceless resource.

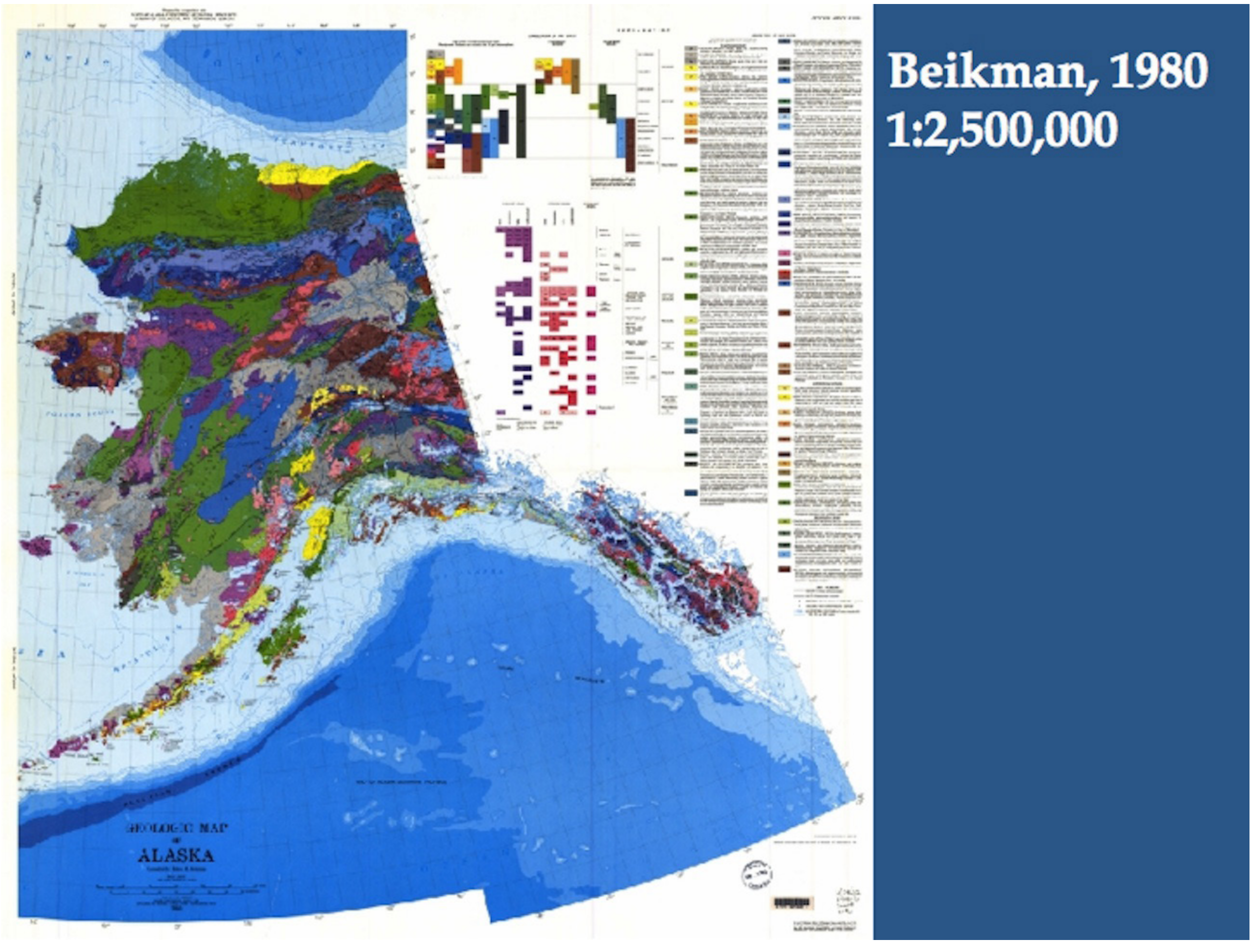
Over the years, Regional Native Corporations, in particular The Aleut Corporation, the Bristol Bay Native Corporation, and the Calista Corporation have provided access to their files, assisting in the map compilation effort.

The National Park Service has been a consistent supporter of this effort and has provided a continuing level of financial support toward production of regional maps that cover Park lands.

The USGS Energy Program was an important contributor to the effort to produce the recent Cook Inlet region map, which helped us to further refine the databases as well as producing new quadrangle maps on the north slope of Alaska (Mull and others, 2004, 2005, 2006a, 2006b, 2008). Also, maps and data provided by the USGS Alaska Volcano Observatory have been a significant help in the Aleutian Islands region of the State.

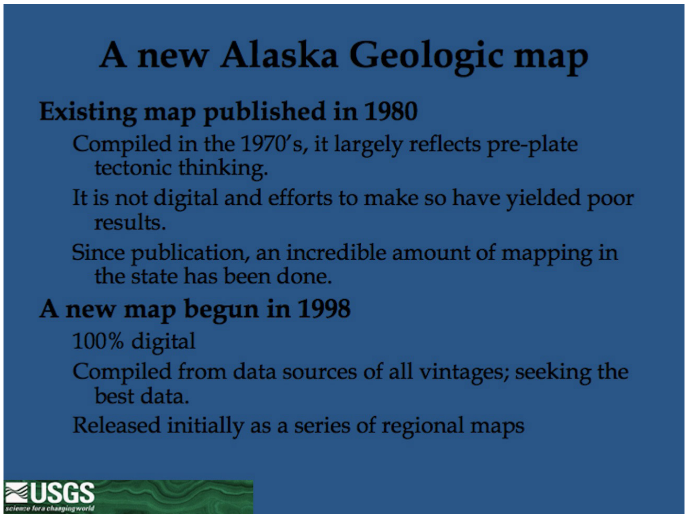


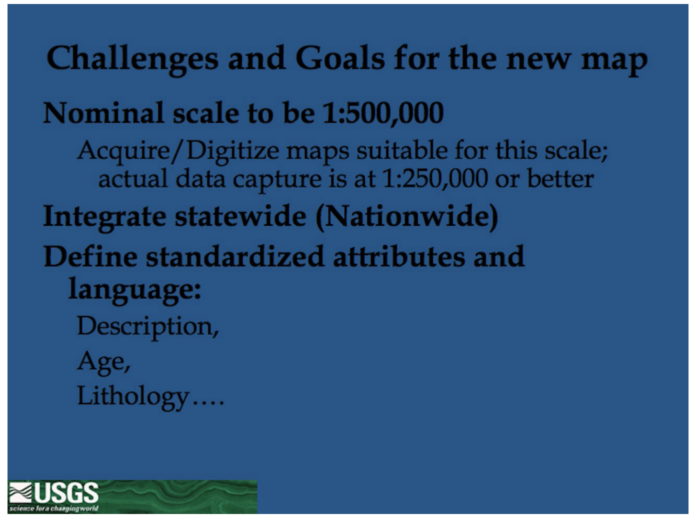
Here, we describe the ultimate goal of the effort, the first digital geologic map of Alaska and the first map that incorporates information and insights developed as a result of plate tectonic theory and the terrane concept.



The effort began as part of the USGS Mineral Resources Program National Surveys and Analysis (NSA) project, which had a national focus and a goal to produce a 50-state compilation. In the conterminous United States, many of the maps produced from the NSA project were simply digitized versions of already-published State maps. In Alaska, we realized that we did not have a suitable State map for this effort; we had the Beikman's (1980) Geologic map of Alaska, as well as a series of earlier 1939 and 1957 vintage state maps. Unfortunately, these maps were all produced in a pre-Plate Tectonic era and do not reflect current thinking.

Additionally, these maps were produced at a scale of 1:2,500,000, but our goal was compilation at 1:250,000 scale, with regional maps published at 1:500,000 scale and the ultimate State map at 1:1,584,000 scale (the traditional Alaska Map B).



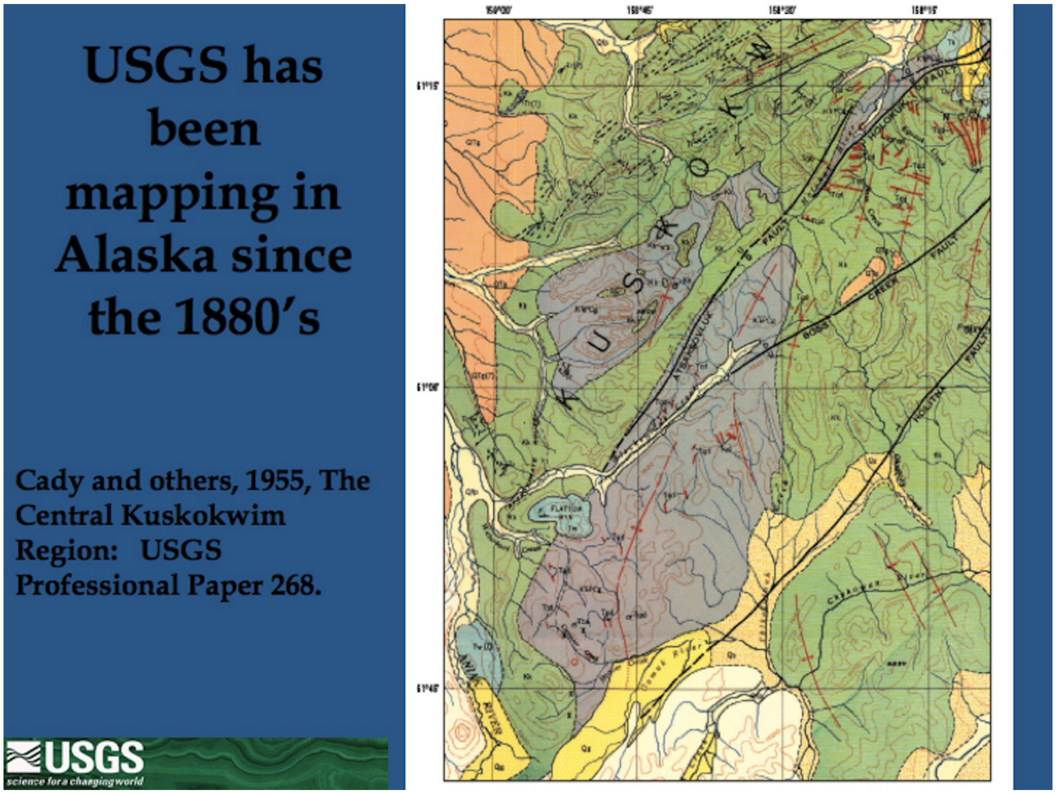


The existing map (Beikman, 1980) was compiled mostly in the early to middle 1970s. Because its sources largely predated plate tectonics, the map reflects pre-plate tectonic thinking. In the 1990s, we tried to digitize the map and encountered many problems; the primary one is that although the latitude and longitude grid printed with the map is a reasonably well-defined Albers Equal Area projection, the map underneath is not. We were never able to discover the projection for the geologic base, and rubber-sheeting was very unsatisfying. Ultimately, we gave up.

One important incentive for abandoning that effort was the publication of a large amount of new mapping as a result of the Alaska Mineral Resource Assessment Program, which was active from about 1975 to 1995. We began the new map compilation effort in 1997, developing the tools as we went, but pressed to produce the first regional map only 18 months later. This was quite a learning experience.

The data sources for the new map have included published geologic map data, original field notes and field sheets, unpublished draft maps, journal articles, remotely sensed data, and various other sources. USGS publications as old as the early 20th century as well as recently published journal articles or even preprints have been incorporated as the map compilation effort progresses. Given the size of the job, we resolved to produce a series of regional maps, to develop our techniques, as well as make data available to users more quickly.

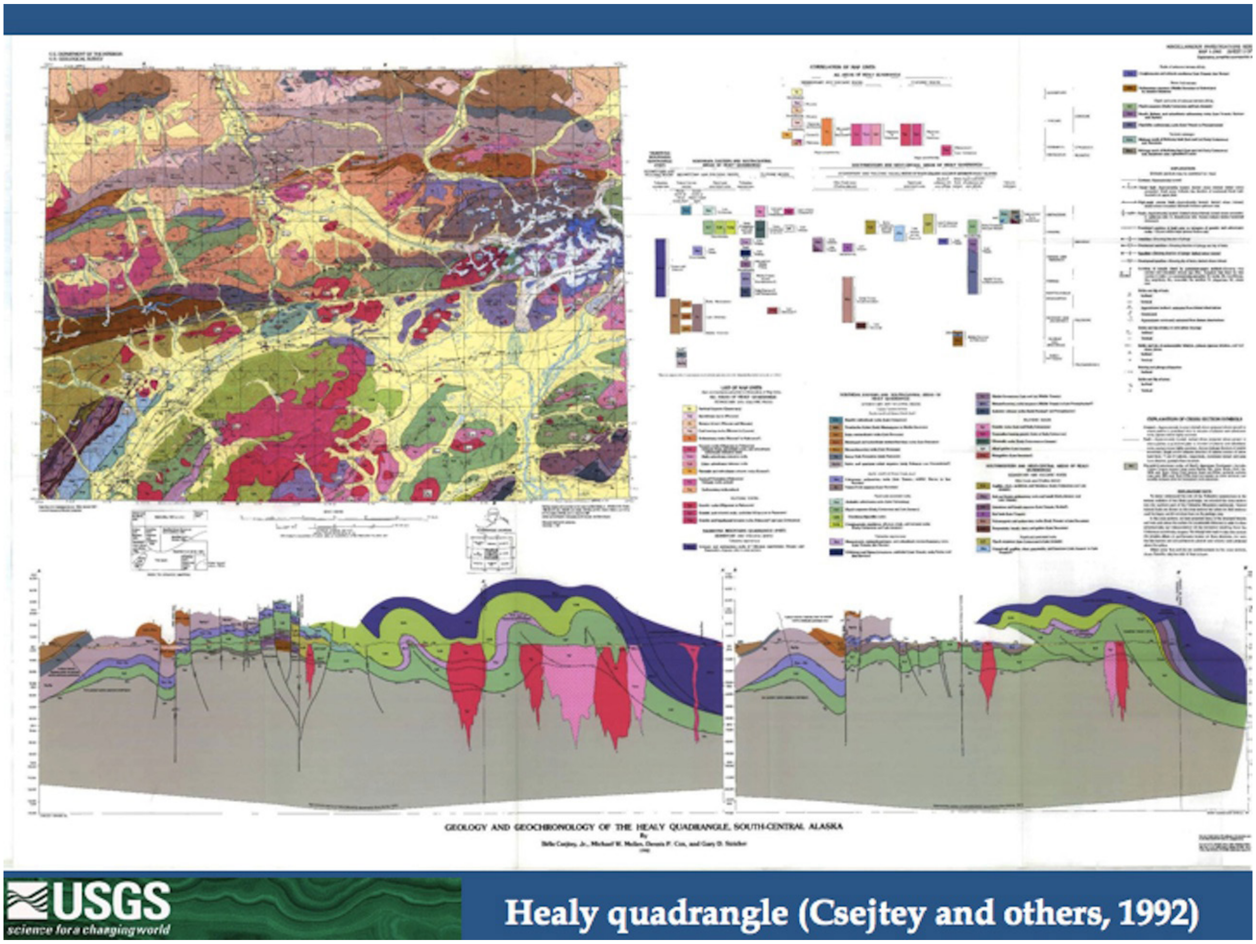
Meanwhile, we worked nationally to set goals and standards for the NSA project. Principally, we would acquire digital geologic map data for all 50 States. It would nominally be at a scale of 1:500,000 and would integrate into a national dataset. We created a standardized attribute schema that included unit age, description, lithology, and other characteristics. And ultimately, all the States would be linked into a seamless database. Most of these goals were met. However, seamlessness is still a challenge, more so in the conterminous United States than Alaska, but it remains a universal issue.



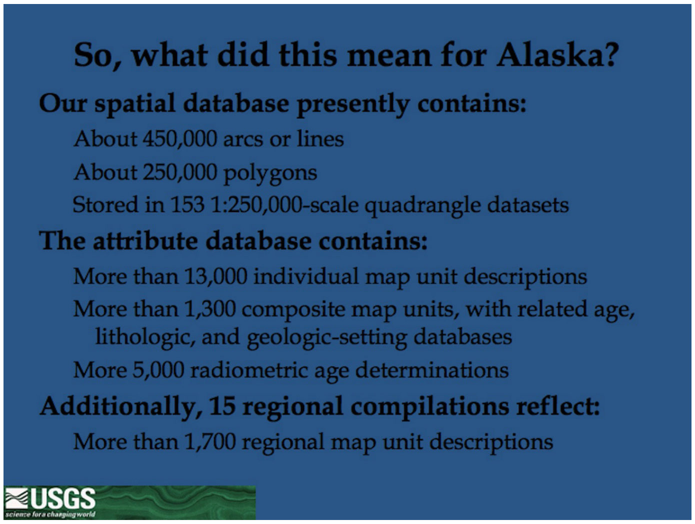
The Alaska effort, which also included Hawai'i, proceeded as part of the overall NSA effort. An attempt at seamlessness was required because we were integrating the geology of 153 1:250,000-scale quadrangle components. In Alaska, we thought of this as the conceptual equivalent of linking 48 conterminous U.S. States together.

The USGS has a long history in Alaska and has been mapping Alaska since the 1880s. As a result, for some areas in Alaska there are many generations of published and unpublished geologic maps. Yet in other areas, there are no published maps at scales more detailed than 1:1,000,000 or 1:500,000.

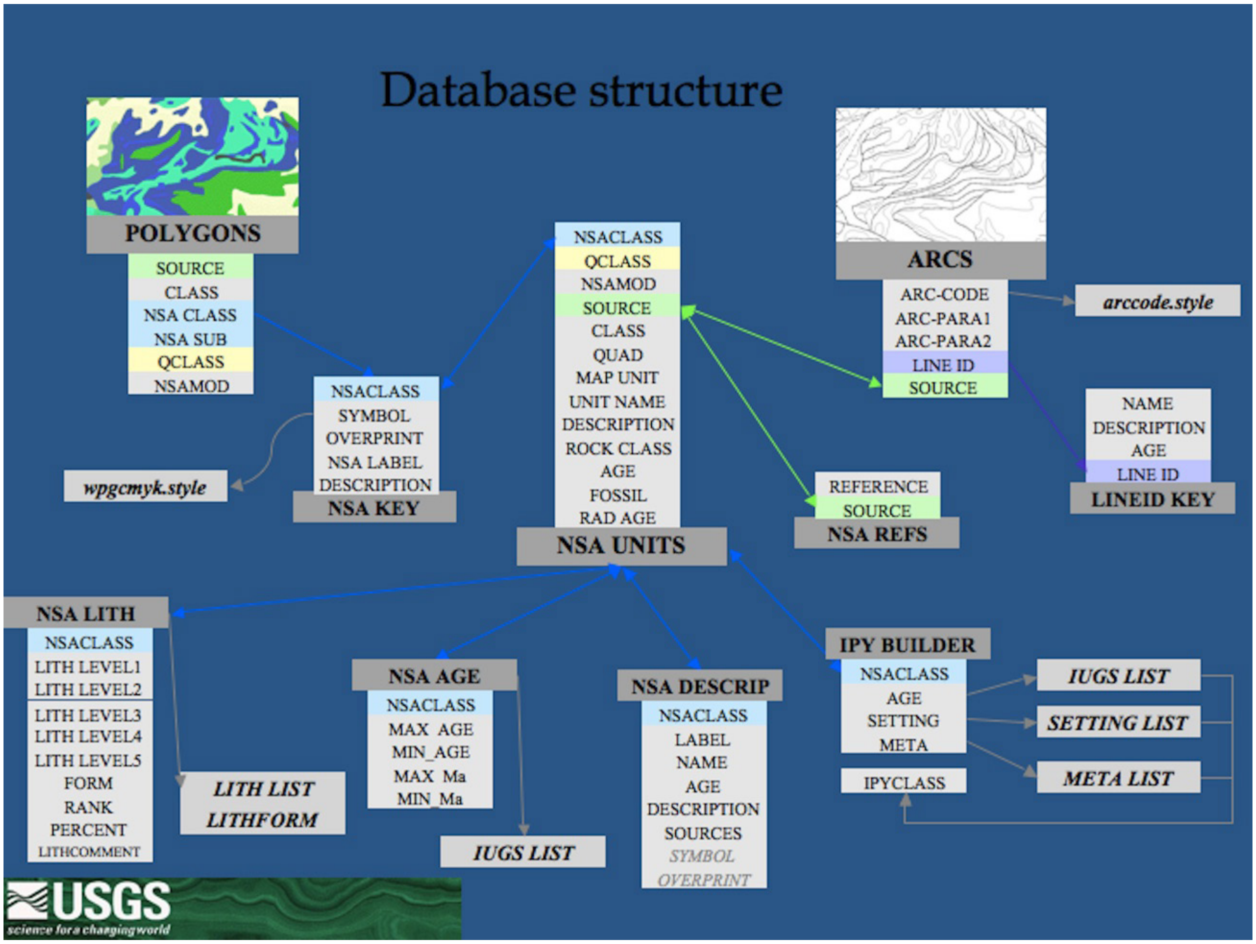
In the area shown in this slide, J.B. Mertie conducted mapping in the 1930s and published his interpretation and data as a USGS Bulletin (Mertie, 1938). The map shown here reflects additional fieldwork during the 1940s and early 1950s, which was published as a USGS Professional Paper (Cady and others, 1955). J.M. Hoare, W.L. Coonrad, and W.H. Condon did additional fieldwork in this area in 1969 and 1970, the DGGS conducted mapping in the 1980s, and Marti Miller and coworkers of the USGS continue to work in this area today. Fundamentally, the mapping is never done.



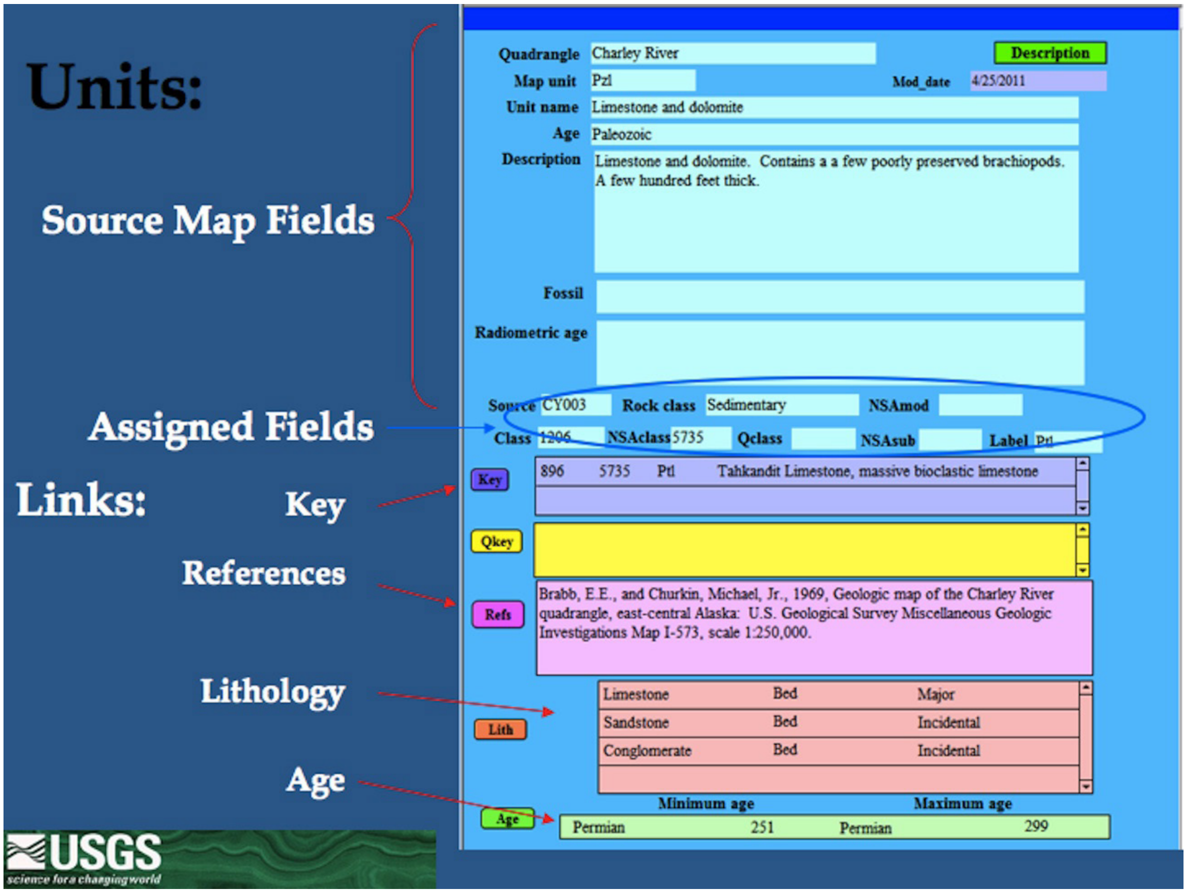
We digitized and incorporated information from those early efforts, as well as recently completed published maps, such as the map of the Healy quadrangle in central Alaska (Csejtey and others, 1992). The best maps we capture provide solid and consistent geologic data and information. Less useful maps are highly interpretive, and recently some are steeped in terrane terminology, obscuring the basic geologic information.



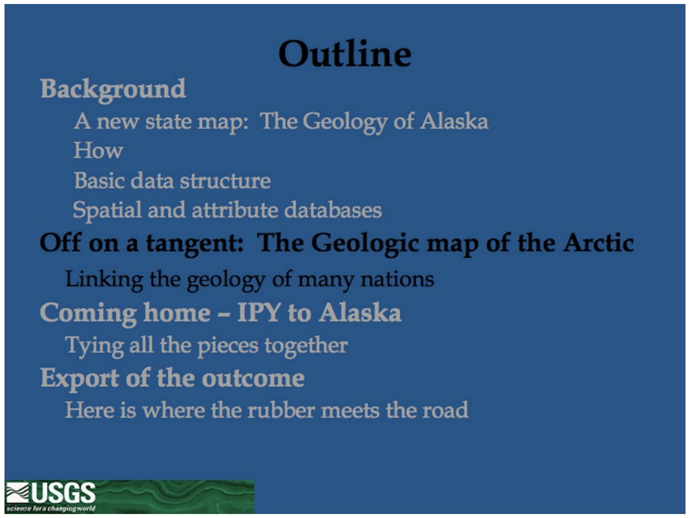
Our first effort was to inventory existing information, in published and unpublished form. What was already digital? Where do we start compiling? How do we structure the data? We had already experimented with creating digital map products on the Alaska Peninsula, so we had some idea what we were getting into. But, in the end we needed to develop a functional and hopefully user-friendly geologic map database that could be used for spatial analysis and as a base for a proposed national mineral resource assessment. To date, the active part of the data is massive; from it we have published 15 regional compilations. As we have moved ahead, some of the map products we initially digitized have been supplanted by better or more detailed sources. Since presentation of this talk, the number of individual map unit descriptions has increased to over 16,000 and more than 7,500 radiometric age determinations have been done.



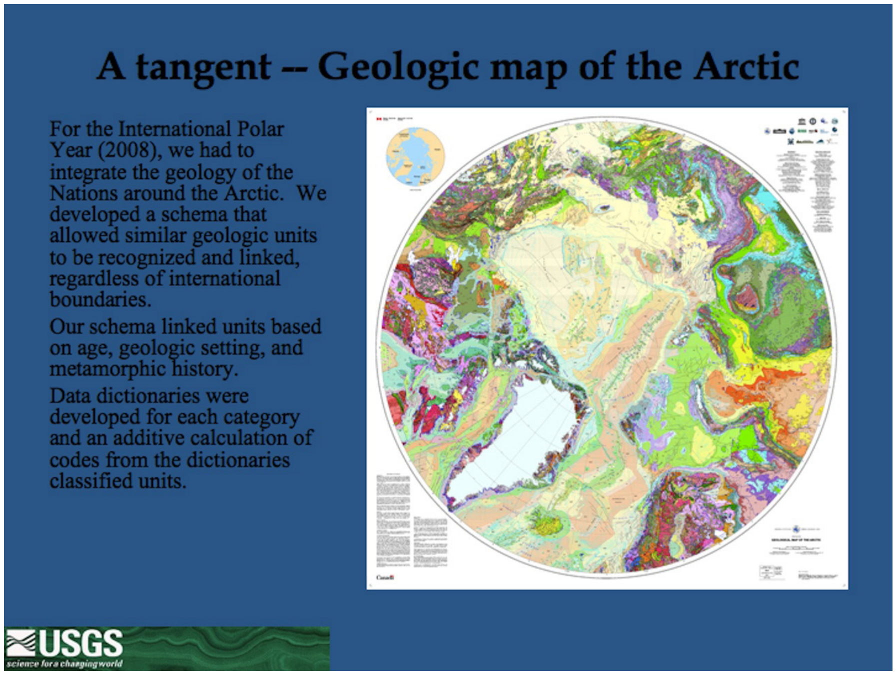
Ultimately, we structured the database around a units table compiled from the source maps. Linked to this units table (containing the 16,000+ unit descriptions) is the source reference through a reference code. The critical link is called "NSACLASS," which links specific geologic units together; for example the Kuskokwim Group, which appears on several maps, is linked across them by a common code. NSACLASS also links map units to unit age, lithology, and geologic settings database tables. For each of these additional attribute tables, explicit data dictionaries were developed to control the vocabulary.



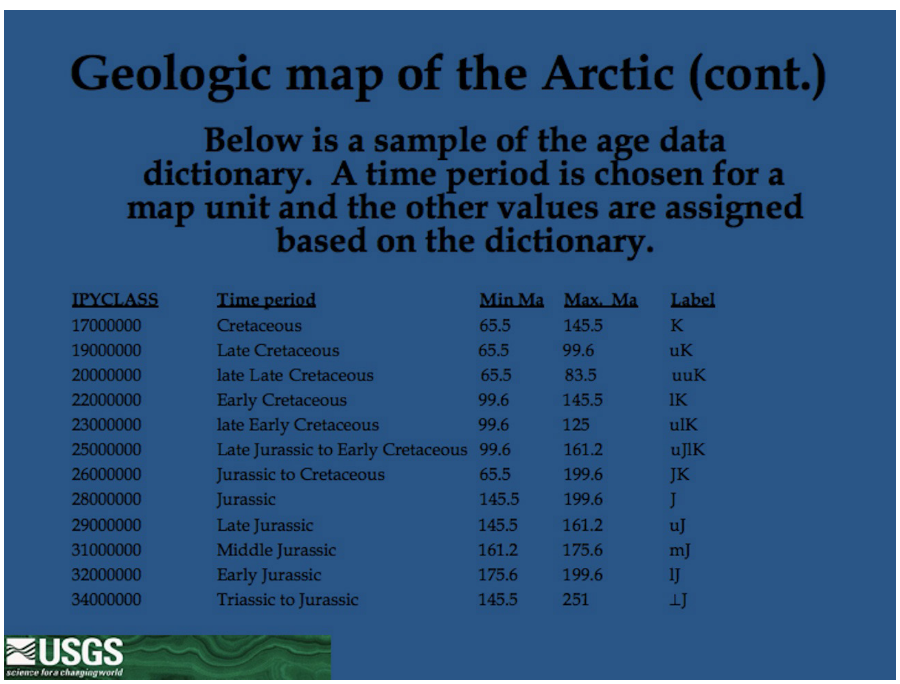
We use a File Maker pro database because it is simple to use and can store unlimited text fields (unlike Access that can only hold 250 characters). The NSAunits table contains the fields that are directly related to the source map. For every source map unit we assign a CLASS value, an NSACLASS, an additional QCLASS for Quaternary map units, and Label. The CLASS value and SOURCE code in combination describe a specific source map unit in the database, which allows us to trace any polygon in the spatial database back to its original source. The NSACLASS is used to integrate all Alaskan geologic maps with one another. The units database is also linked to many of the other tables.



Late in the process of acquiring data for the State map, we became part of an effort to develop a new Circum-Polar bedrock geologic map for the International Polar Year (2008). This map was to cover the north-Polar region of the Earth from 60 degrees north. The challenge here, beyond the politics, was not only to link the geology for many of the 153 1:250,000-scale quadrangles of Alaska together, as the map area covered the majority of Alaska, but to link our geology to that of all countries in the Polar region. National mapping styles, philosophies of what constitutes a geologic map, and even cultural differences all had to be integrated into a seamless whole. As part of the Alaska map effort, we had already developed a schema to integrate the published geologic map of the Yukon, Canada, so we had already begun to travel down the path.

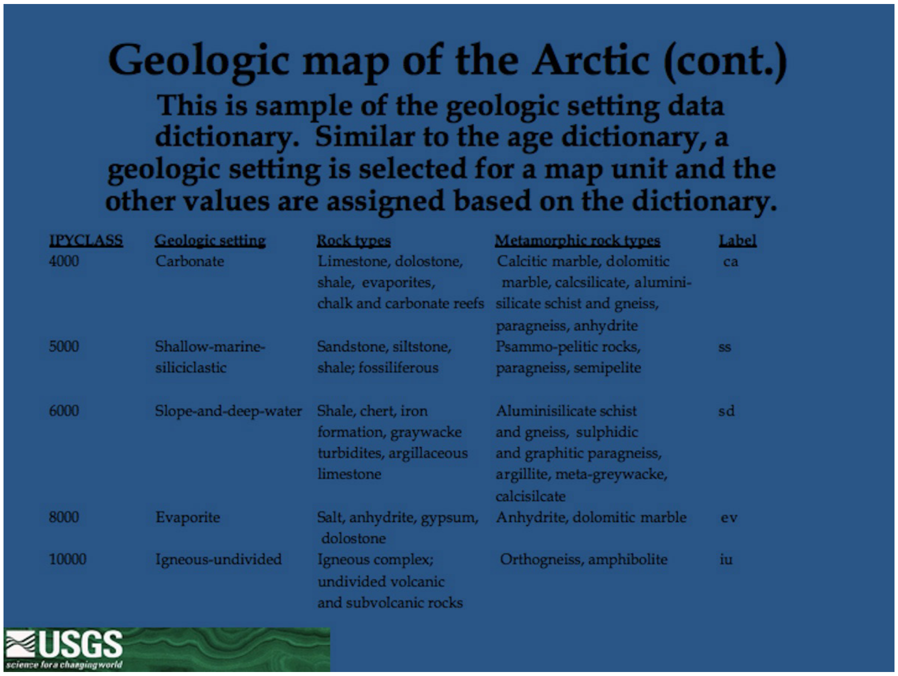


For the International Polar Year (2008), we had to integrate the geology of the Nations around the Arctic. We developed a schema that allowed similar geologic units to be recognized and linked, regardless of international boundaries. Our schema linked units based on age, geologic setting, and metamorphic history. Data dictionaries were developed for each category and an additive calculation of codes from the dictionaries classified units.

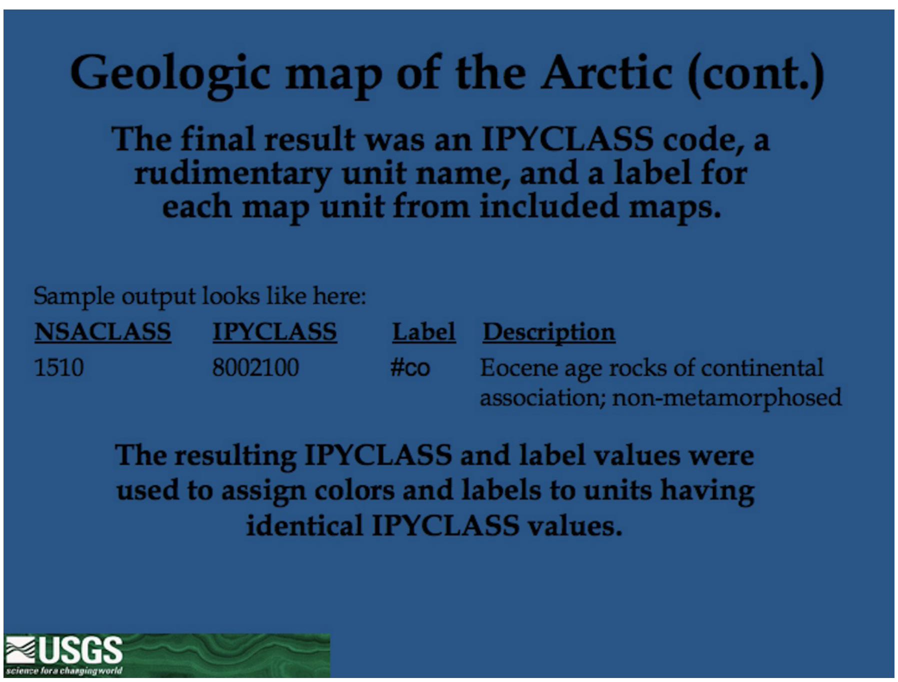


IPYCLASS	Time period	Min Ma	Max. Ma	Label
17000000	Cretaceous	65.5	145.5	K
19000000	Late Cretaceous	65.5	99.6	uK
20000000	late Late Cretaceous	65.5	83.5	uuK
22000000	Early Cretaceous	99.6	145.5	lK
23000000	late Early Cretaceous	99.6	125	ulK
25000000	Late Jurassic to Early Cretaceous	99.6	161.2	uJlK
26000000	Jurassic to Cretaceous	65.5	199.6	JK
28000000	Jurassic	145.5	199.6	J
29000000	Late Jurassic	145.5	161.2	uJ
31000000	Middle Jurassic	161.2	175.6	mJ
32000000	Early Jurassic	175.6	199.6	lJ
34000000	Triassic to Jurassic	145.5	251	⊥J

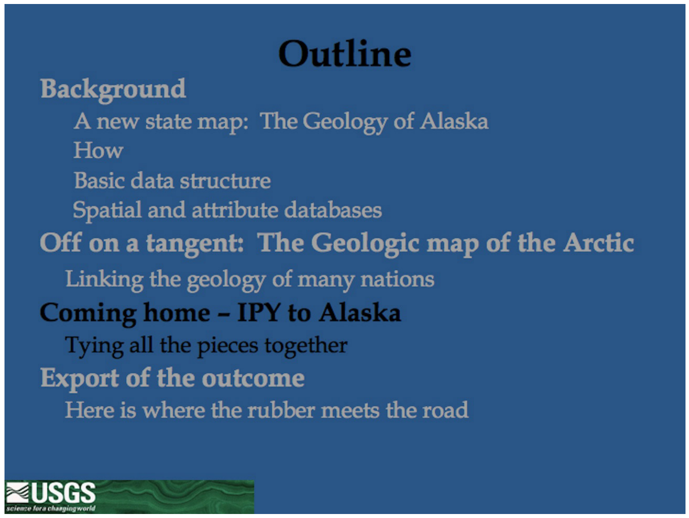
Each of the categories in the schema was assigned a range of numbers, such that when all categories are combined, the assigned IPYCLASS specifies uniquely the classification of the map unit.



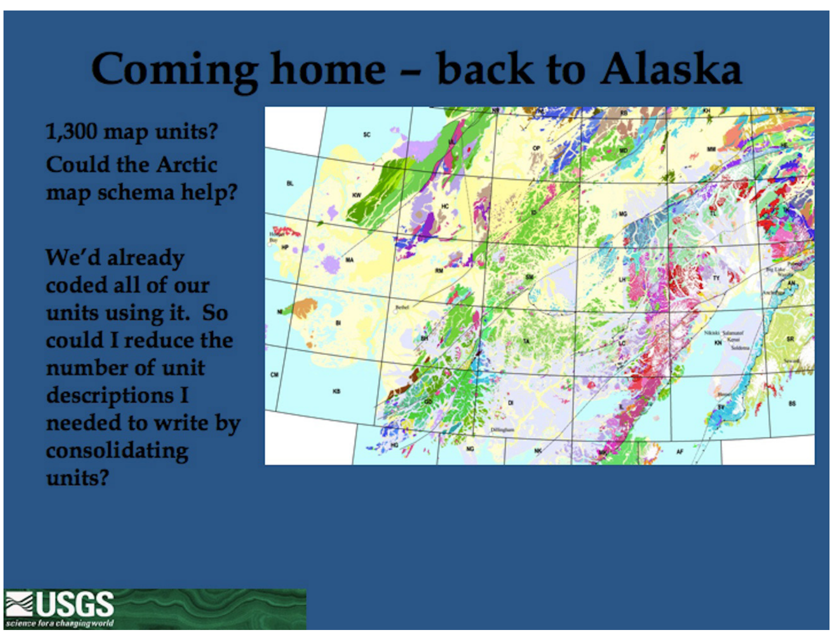
The lithologic classification was based on the rock types expected in a given geologic environment or setting.



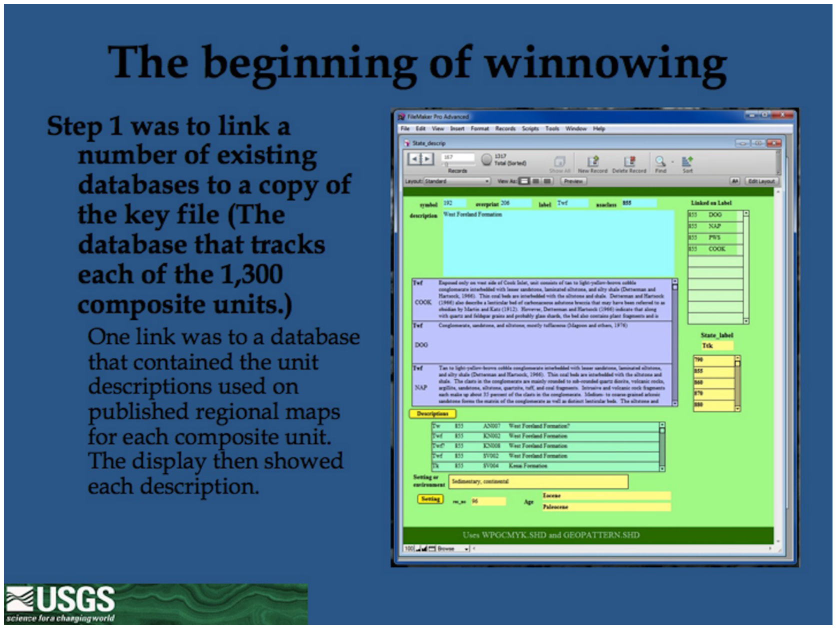
The final result was an IPYCLASS code, a rudimentary unit name, and a label for each map unit from included maps. The resulting IPYCLASS and label values were used to assign colors and labels to units having identical IPYCLASS values. Of course, units can be grouped on the basis of similar IPYCLASS values at user discretion. [NOTE: In the Label code "#co," the "#" should be the symbol for Eocene.]



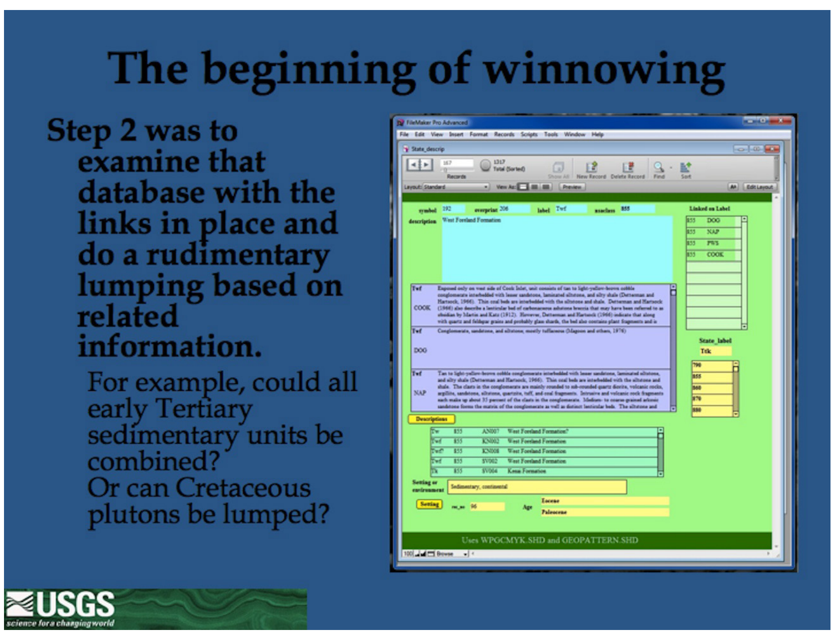
Having completed the IPY effort, our primary focus returned to the Alaska map. Our thought was, during the IPY effort, we had used the database to create the unit descriptions used on the map. Realizing that these unit descriptions were extremely succinct, if not cryptically abstracted, we wondered if the database could help us produce more complete unit descriptions. So, we developed another linked database, hopefully to pull everything together, leveraging off of the IPY coding we had done and seeing where it took us.



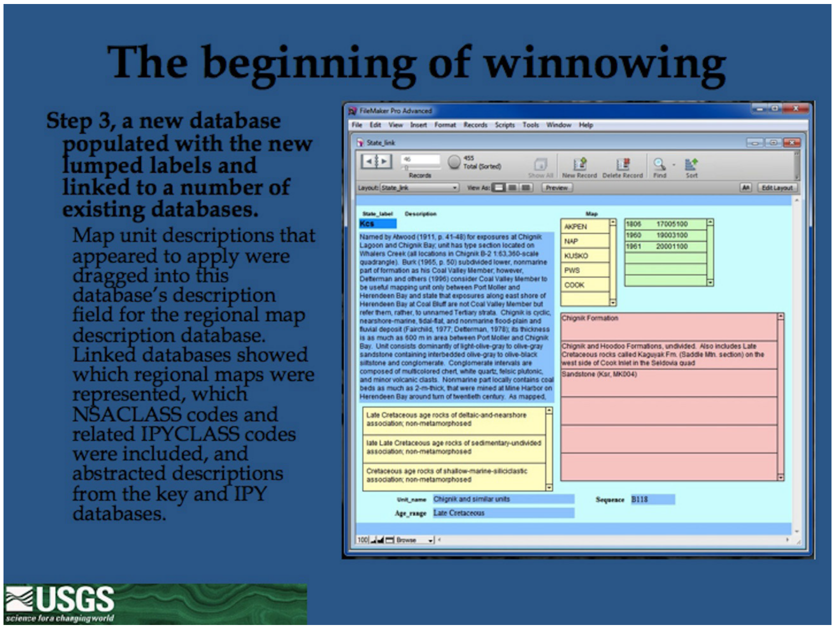
At this point in the process, the Alaska map had 1,300 map units. Because the Alaska and Circum-Polar map shared the same map unit coding scheme, the Alaska map units were consolidated according to the process described below.



Step 1 was to link a number of existing databases to a copy of the key file (the database that tracks each of the 1,300 composite units). We added a view into the database that included the unit descriptions from each of the regional maps; as these all had assigned NSACLASS values already, this was a simple step. One link was to a database that contained the unit descriptions used on published regional maps for each composite unit. The display then showed each description. This view not only showed the complete unit description from each regional map based on assigned NSACLASS, but it also showed a list of which regional maps contained the unit. A new field was added, called "State Label," which nominally would be the label for this unit used on the final State map.



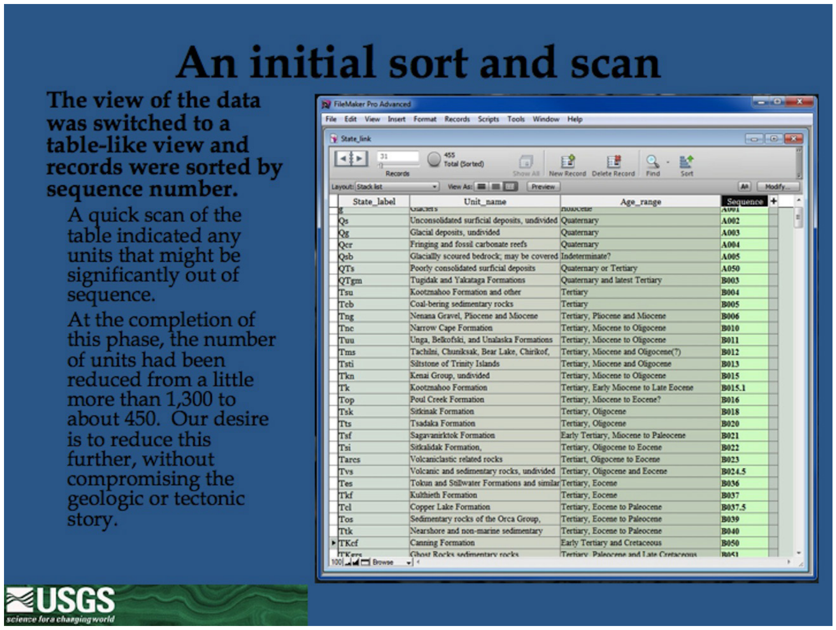
Step 2 was to examine that database with the links in place and do a rudimentary grouping based on related information. For example, could all early Tertiary sedimentary units, or all Cretaceous plutons, be combined? The new State Label field would become the link tying selected NSACLASS values together for the eventual State map. It was recognized that Tertiary sedimentary units were too varied to group all together, but based on descriptions, some certainly could be. The NSACLASS values from Cretaceous plutons originally divided them into three age classes and four to six compositional ranges. However, there was enough overlap compositionally that some of these could be readily combined for the developing State map.



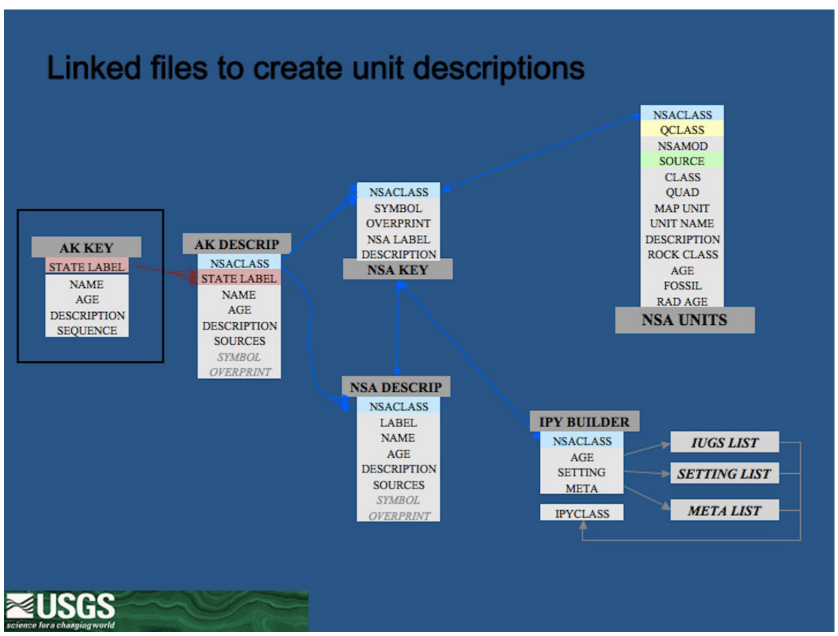
Step 3, a new database (table) was populated with the new grouped labels and linked to a number of the existing databases. The key link was through the State label to the NSAKEY field; this is a "1 to many" relation and, through the NSAKEY value, ties to NSACLASS and makes the other database tables accessible.

Map unit descriptions from the regional maps that appeared to apply to the unit statewide were brought into this database's description field (the blue one in the figure) from the regional map description database. Linked databases showed which regional maps were represented in the statewide unit (the upper yellow box), which NSACLASS codes and related IPYCLASS codes were included in it (the green box), and abstracted descriptions from the key and IPY databases (the pink and lower yellow boxes, respectively).

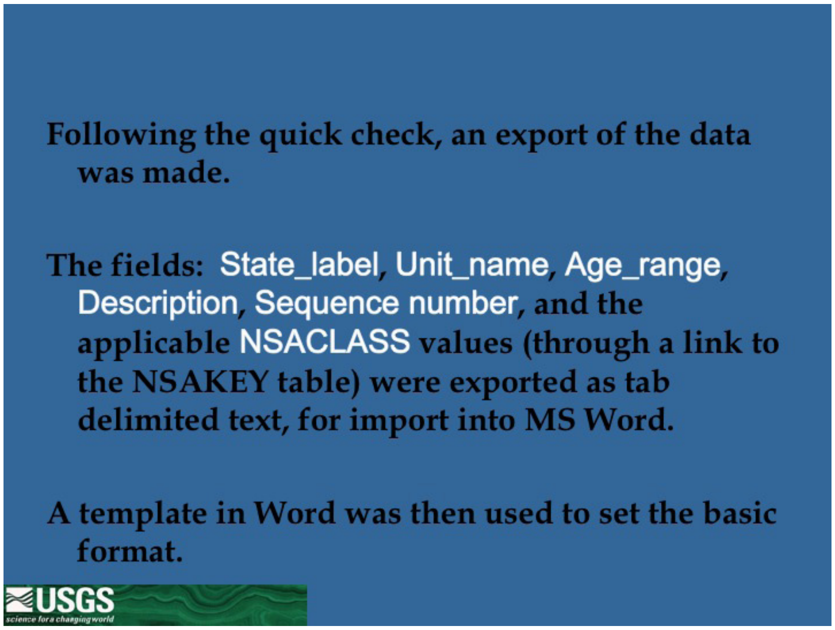
A unit name and age range for the unit were added and a sequence code was assigned to nominally set the order in which units would appear in the Description of Map Units for the State map. The sequence code was a combined letter and number, "A" for Quaternary unconsolidated deposits map units, "B" for sedimentary rock units, "C" for volcanic rock units, "D" for plutonic rock units, "E" for metamorphic rock units, and "F" for tectonic units (such as mélange) as well as problematic rock units, that is, those that did not seem to fit anywhere else.



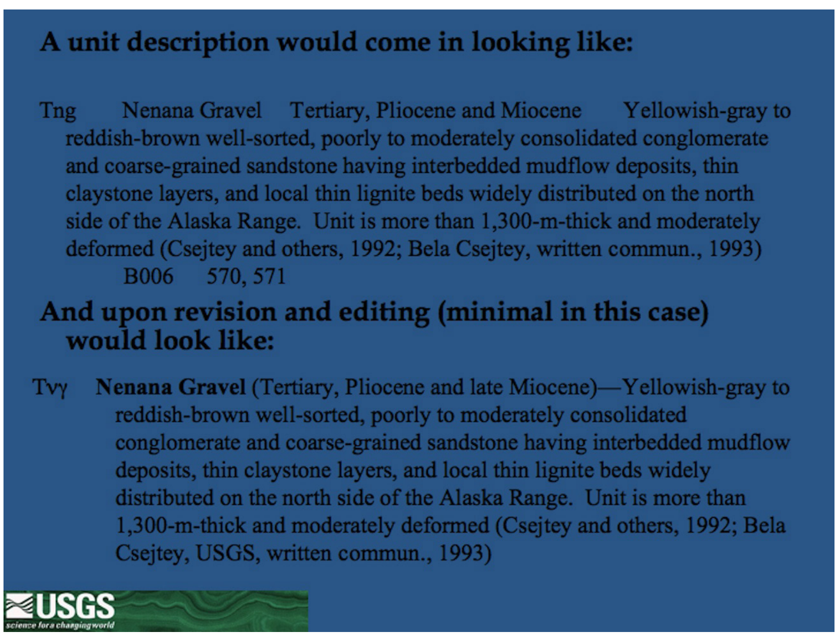
The view of the data then was switched to a table-like view and records were sorted by sequence number. A quick scan of the table indicated any units that might be significantly out of sequence. At the completion of this phase, the number of units had been reduced from about 1,300 to about 450. Our desire is to reduce this further, without compromising the geologic or tectonic story. As the draft map unit descriptions are fleshed out, occasionally it has been necessary to reassign NSACLASS codes, do additional grouping or splitting, and revise sequence codes as we refine the age for the units.



The files that were linked to derive the draft unit descriptions all tied back to the original units database through the NSACLASS code. They also tied to each of the previously written unit descriptions for the regional compilations as well as to the IPYCLASS codes. So, using a database table eventually named “State_link,” I was able to readily view much of the information that I needed to refine the unit descriptions.

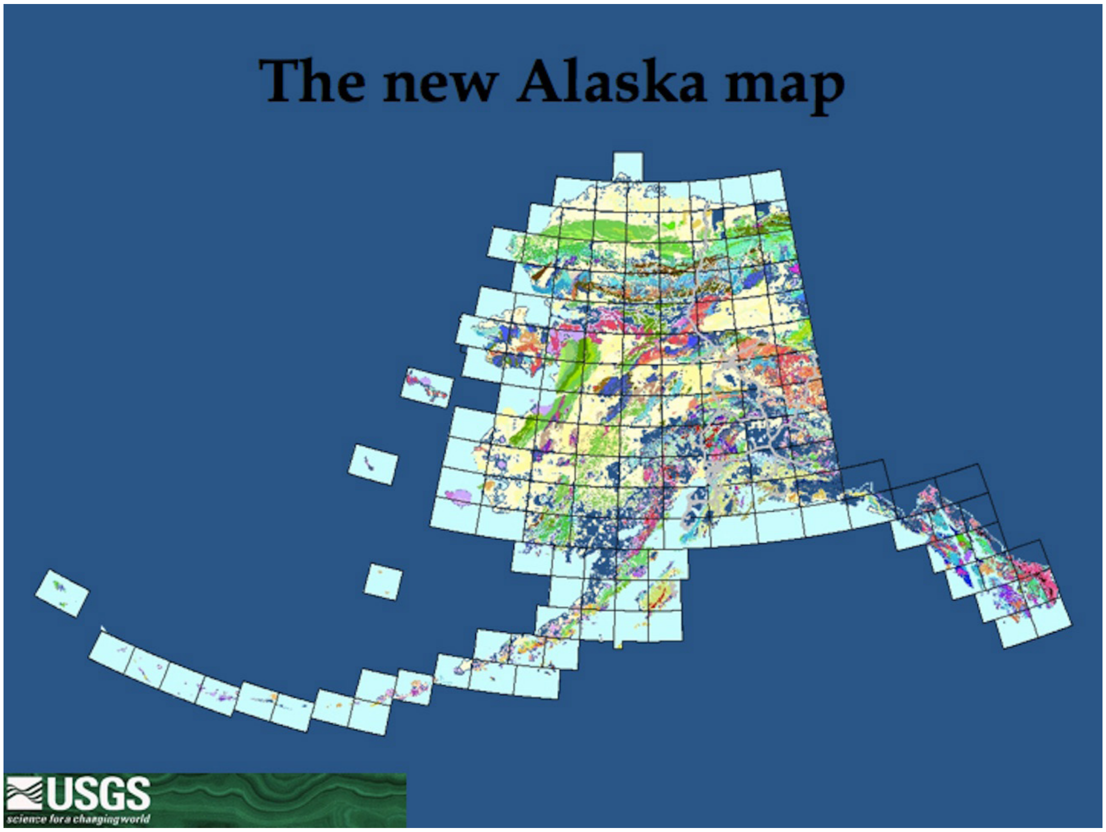


Following the quick check, an export of the data was made as a tab delimited text file for import to MS Word. The exported fields were: State_label, Unit_name, Age_range, Description, Sequence number, and the applicable NSACLASS values through a link to the "NSAKEY" table. Then, the USGS template for map descriptions was attached to set the basic format of the unit descriptions.



The unit description would initially look like this (with field names added here in brackets): Tng [Unit label] Nenana Gravel [Unit name] Tertiary, Pliocene and Miocene [Unit age] Yellowish-gray to reddish-brown well-sorted, poorly to moderately consolidated conglomerate and coarse-grained sandstone having interbedded mudflow deposits, thin claystone layers, and local thin lignite beds widely distributed on the north side of the Alaska Range. Unit is more than 1,300-meter-thick and moderately deformed (Csejtey and others, 1992; Bela Csejtey, USGS, written commun., 1993) [Draft description] B006 [Sequence number] 570, 571 [Applicable NSACLASS values].

The text would then be edited for clarity, the Sequence number and NSACLASS values formatted as hidden text, and the revised description pasted back into the database. As needed, references would be added to a references-cited list in the document, and a list of place names would be maintained in the document in order to facilitate ensuring that the final map contained all necessary place names.



This is a draft of the planned map; as the number of units is gradually winnowed down, the map may become simpler in appearance, yet its digital version will retain the full source information.

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The National Geologic Map Database Project—2010 and 2011 Report of Progress

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Introduction

Development and management of science databases for support of societal decision making and scientific research are critical and widely recognized needs. The National Geologic Mapping Act of 1992 (*http://ncgmp.usgs.gov/about/ngm_act/ngmact1992.html*) and its subsequent reauthorizations stipulate creation and maintenance of a National Geologic Map Database (NGMDB, *http://ngmdb.usgs.gov*) as a national archive of spatially referenced geoscience data, including geology, paleontology, and geochronology. The Act further stipulates that all new information contributed to the NGMDB should adhere to technical and science standards that are to be developed as needed under the guidance of the NGMDB project. Development of a national database and its attendant standards is a daunting task requiring close collaboration among all geoscience agencies in the United States, at the State and Federal levels. The Act, therefore, creates the environment within which the U.S. Geological Survey (USGS) and the Association of American State Geologists (AASG) can collaborate to build the NGMDB and also serve the needs of their own agencies.

The Congressional mandate for State-Federal collaboration on the NGMDB has proven invaluable, facilitating progress on many technical issues that would otherwise have been much more difficult to achieve by separate efforts within agencies. The NGMDB's long record of accomplishment owes a significant debt to its many collaborators and to the institutions with which it interacts (see Appendix A of previous year's Reports of Progress). At numerous meetings during the year, technical plans and progress are reported, and discussion and comment is requested; these activities are recorded each year by a progress report in the DMT Proceedings. In order to minimize repetition in this report, we have limited the background and explanatory information, which are contained in previous reports of progress (see Appendix B of earlier reports; in particular the 2005 report). However, some repetition is necessary here in order to provide background for first-time readers.

Strategy and Approach

From the guidance in the National Geologic Mapping Act, and through extensive discussions and forums with the geoscience community and the public, a general strategy for building the NGMDB was defined in 1995 (see Soller and Berg, 1995 and 1997, in the Appendix). Based on continued public input, the NGMDB has evolved from that concept to a set of resources that substantially helps the Nation's geological surveys provide to the public, in a more efficient manner, standardized digital geoscience information.

The NGMDB is a suite of related databases, products, and services consisting of: (1) a Map Catalog containing information and Web links for all paper and digital geoscience maps and related reports of the Nation, and images of many of these maps; (2) the U.S. Geologic Names Lexicon; (3) the Mapping in Progress Database; (4) nationwide geologic map coverage at intermediate and small scales; (5) a prototype online database of geologic maps (containing data predominantly in vector format); (6) a set of Web interfaces to permit access to these products; and (7) a set of standards and guidelines to promote more efficient use and management of spatial geoscience information. The NGMDB system is a hybrid—some aspects are centralized and some are distributed, with the map information held by various cooperators (for example, the State geological surveys). Through a primary entry point on the Web, users can browse and query the NGMDB, and obtain access to the information wherever it resides.

The project's success depends on the strong endorsement and collaboration of management and technical consultants in the USGS and AASG. This support is critical because: (1) the project has responsibility for standards development, and standards cannot successfully be implemented until they are widely endorsed; (2) many of the various project tasks are at least partly conducted by collaborators rather than by funded project members; and (3) this project is national in scope and does not fit cleanly into the USGS Regional organizational structure. The project therefore relies on USGS and AASG management to implement and maintain certain policies and standards that support NGMDB objectives and to help promote constructive interaction with new initiatives whose objectives may be similar (for example, the USGS National Geological and Geophysical Data Preservation Program; the National Science Foundation (NSF)-funded U.S. Geoinformatics Network project).

Example "Outcomes"

In yearly proposals for project funding, the USGS requires that three examples of a project's impact and contributions be provided. They are included here.

1. On a monthly basis, the NGMDB Web site receives 90–100,000 visits from about 25,000 users (nearly all non-USGS). This high level of Web traffic spawns numerous user requests for information and assistance—these users vary widely in interest and background, and include schoolchildren, homeowners, local government planners, and professional geologists. Users mostly access the NGMDB data-discovery databases (Map Catalog, Geolex, Mapping in Progress) to find geoscience maps and publications. Many of these users are contacted personally by email to ensure they find what they need.

2. Public interest in two national map databases published by the NGMDB project in 2010 remains high. These are databases for: (1) the Geologic Map of North America (GMNA, Garrity and Soller, 2009), and (2) Surficial Materials of the conterminous United States (Soller and others, 2009). In response to this interest, a resources page for the GMNA was developed (*http://ngmdb.usgs.gov/gmna/*) to provide access to the numerous file formats (for example, shapefiles, Google Earth) requested by users after formal publication in Esri Geodatabase format. The resources page also addresses the emerging uses for the GMNA in various Web Mapping Services. Similar requests for the Surficial Materials database are being handled informally, but a resources page also may be developed.

3. For 16 years, the NGMDB project has organized annual workshops on "Digital Mapping Techniques." The workshops mostly support the needs of State and Federal agencies, for information exchange and for development of more efficient methods for digital mapping, cartography, GIS analysis, and information management. These workshops have been very successful and have significantly helped the geoscience community converge on more standardized approaches for digital mapping and GIS analysis. The workshop Proceedings are widely read and consulted for technological advances and trends. As a response to information learned at these workshops, agencies have adopted new, more efficient techniques for digital map preparation, analysis, and production—examples are numerous; here is one from the first DMT meeting: "After attending the Digital Mapping Techniques '97 (DMT '97) conference in Lawrence, KS, we decided to model our digital cartographic production program after that of the Nevada Bureau of Mines and Geology ...[which] expedited our overall cartographic production. Months of trial-and-error digitizing and interaction between geologists and technicians were replaced by a single scanned image that could be quickly drafted. In about two weeks, the 1:24,000 Alameda geologic quadrangle went from an inked mylar to a multicolor plotted map sheet, complete with cross sections." Although this quote is now 16 years old, these same sentiments were expressed at the DMT'12 meeting.

Project Organization

This project has been designed as a set of related tasks that will develop, over time, a NGMDB with increasing complexity and utility. This endeavor is being accomplished through a network of geoscientists, computer scientists, librarians, and others committed to supporting the objectives of the NGMDB. Since the project's inception, the plan for its design has been described in three phases. This approach has served to communicate the general plan, but as the project evolved in response to changing technology and to changing perceptions regarding its proper role in support of the U.S. geoscience community, the three-phase design became somewhat misleading. These three phases are now more accurately referred to simply as tasks and are executed concurrently.

Task One (formerly "Phase One") principally involves the building of a comprehensive Map Catalog of bibliographic records and online images of all available paper and digital maps and book publications containing maps and related information that adhere to the earth-science themes specified in the National Geologic Mapping Act of 1992. Development and maintenance of the U.S. Geologic Names Lexicon (Geolex) is an essential component of Task One, serving as a foundation for the Nation's geologic mapping science. This task also includes related activities such as design and maintenance of the Mapping in Progress Database. ***Task Two*** (formerly Phase Two) addresses development of standards and guidelines for geologic map and database content and format. ***Task Three***

(formerly Phase Three) is a long-term effort to develop a database (principally vector, geographic information system (GIS)-compatible information) that contains national, regional, and detailed geologic map coverage managed according to a complex set of content and format specifications that are standardized through general agreement among all partners in the NGMDB (principally the AASG); this database will be integrated with the databases developed in Task One.

The NGMDB project's technology and standards development efforts also are coordinated with various related entities, including the Federal Geographic Data Committee, Esri Inc., the USGS Geological and Geophysical Data Preservation Program, the NSF-funded Geoinformatics project (GIN), the North American Geologic Map Data Model Steering Committee, the International Union of Geological Sciences (IUGS) Commission on the Management and Application of Geoscience Information (CGI), the IUGS Commission on Stratigraphy, and the IUGS-affiliated Commission for the Geological Map of the World.

A full realization of the project's Task Three 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 the NGMDB, extensive work will be conducted to develop Web interfaces and search engines and to continually improve them, and to develop the data management and administrative protocols necessary to ensure that the NGMDB will function efficiently in the future. The NGMDB's databases and project information are found at *http://ngmdb.usgs.gov*.

Progress in 2010 and 2011

Task One

A wealth of geoscience information is available in various paper and digital formats. With the emergence of the Internet and 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 readily understood by 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, the utility of the information 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, and new types of demands from the user community. To help address these challenges, this task provides 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 2010 include:

1. Began the first major redesign of all NGMDB databases and Web pages since the project began 15 years ago. This work was undertaken in order to reduce system maintenance and to provide users with greatly enhanced search and display options. As the first step in redesigning the NGMDB database and Web site, Map Catalog and Geolex citations were merged into a single Oracle database to provide integrated search and reporting of publications, geologic names, and study area footprints. Citations were error-checked against USGS Publications Warehouse (PW) citations, and errors in both NGMDB and PW systems were corrected. The majority of citation revisions were completed, and the merged database is being prepared to serve the redesign's next step—enhanced database search and reporting capabilities.

2. Expanded the Map Catalog by ~67,00 records, to a total of ~89,500 records. 1,500 records are new publications. 5,200 were added from Geolex when their citations lists were merged. The Catalog now includes 40,000 USGS publications, 31,600 State geological survey publications, and 17,900 by other publishers.

3. Engaged all States in the process of entering Map Catalog records. Processed ~658 new records for State geological survey publications.

4. In response to NCGMP and AASG requests, and in part to address NCGMP performance metrics required by the Office of Management and Budget, provided: (a) index maps showing areas in the United States that have been geologically mapped at various scales and time periods, and (b) computations including the number of square miles geologically mapped at intermediate and more detailed scales (see Soller, 2005). Helped NCGMP to revise their metrics, to better measure annual and cumulative productivity in geologic mapping.

5. Collaborated with the USGS Publications Warehouse (PW) on publication-tracking, database-compatibility, and image-processing issues, to minimize duplication of effort and to better integrate the two systems. Collected from various donors, organized, and shipped to the PW a palette of USGS publications, to be scanned and put online.

6. Continued to add to Map Catalog the Web links to online digital maps and reports. 41,000 publications (46 percent of the Catalog's content) now have at least one link. Many publications have multiple links to individual map sheets. Contributed to the PW more than 3,000 links to online publications to insert into their citation pages.

7. Scanned, processed, and loaded into the Map Catalog about 2,200 map images.

8. Public requests for map images in various formats prompted initial phase of development work on a complex

set of methods to bulk-process thousands of images into: (a) TIFF, (b) PDF, containing metadata from the Map Catalog; (c) JPEG; and (d) MrSID.

9. Hand-assembled a high speed computer to replace the current image-processing machine and maintained a 12-TB disk array for storage of map images. This computer will process all scanned maps into various formats.

10. Researched, acquired, and began configuring two servers and a 36-TB disk array. This upgrade of the computing infrastructure will permit significantly better services to be offered to the public (for example, the image formats noted above).

11. Continued to revise existing records in Geolex. Given the many and disparate origins of this Lexicon, revision of existing electronic records inherited from the last-published USGS listing of names (in USGS DDS-6) remains the focus of work. As time permits, critically important stratigraphic information (for example, type localities) is retrieved from the authoritative-published USGS lexicons (for example, Bulletins 896 and 1200) and integrated into Geolex. To support this work, Bulletins 896 and 1200 were scanned and OCRed under contract.

12. Revised and reissued contract to scan the Geologic Name Committee's (GNC) master card file of geologic names (~220,000 cards, located in Reston, VA). This collection will be a valuable supplement to Geolex, especially regarding relevant publications for geologic names. Continued to scan and process Menlo Park's collection of GNC cards, which are an invaluable complement to the Reston set.

13. With collaboration from the Wyoming Geological Survey and Esri, developed a prototype application using Esri's ImageServer and demonstrated it at the DMT'10 meeting. This application provides a visualization of available geologic maps of Wyoming and links to the Map Catalog Product Description Page for each map. The application provides a new means of access to the Catalog and will facilitate searching and downloading of map images in various formats. It is anticipated that this initiative will be greatly expanded in future years.

14. Continued to revise the Web statistics that identify the extent to which State geological survey publications are accessed via the Map Catalog. These statistics are now provided to each State geologist via a password-protected site.

15. Customer service: Completed several hundred productive interchanges with Map Catalog and Geolex users via the NGMDB feedback form and other mechanisms.

Specific accomplishments in 2011 include:

1. As the first step in redesigning the NGMDB database and Web site, Map Catalog and Geolex citations were merged into one database, to provide integrated search and reporting of publications and geologic names. This tedious process is essentially complete, but extensive quality checking continues in order to improve the content. Continued to error-check against USGS Publications Warehouse (PW) citations, and reported errors to their staff.

2. Expanded Map Catalog by ~1,800 records, to total of ~91,350 records (86,900 are now error-checked and publicly available). Includes 40,700 USGS publications, 32,500 State geological survey publications, and 18,000 by other publishers.

3. Engaged all States in process of entering Catalog records. Processed ~900 new records.

4. From Map Catalog data, provided index maps and statistics (for example, square miles mapped) to NCGMP and AASG. Helped NCGMP to revise their metrics in order to improve their estimates of annual and cumulative productivity in geologic mapping.

5. Collaborated with PW on publication-tracking and image-processing issues, to minimize duplication of effort and to better integrate the two systems. A palette of USGS publications sent to PW last year is now scanned to be put online.

6. Proposed to USGS Library and PW some conventions for file-naming and file document metadata to be used for all files provided by NGMDB. Concurrence was achieved, and these partners will use similar conventions.

7. Continued to add to Map Catalog the Web links to online digital maps and reports. 43,700 (48 percent) of publications now have at least one link. Many publications have multiple links to individual map sheets.

8. Scanned, processed, and loaded into the Map Catalog almost 4,000 map images.

9. Started production work on collection of georeferenced maps (~5,000 added this year) to be made available via the Catalog and a Web map interface. Prototyped the site and wrote software to efficiently georeference the maps.

10. To address user requests for map images in various formats, designed a complex set of methods to bulk-process thousands of images into TIFF, PDF, and JPEG. Conventions noted in no. 6 were implemented using new software written for this task.

11. Configured two new servers and 36-TB disk array that will manage the NGMDB database and all scanned maps. Owing to infrastructure issues in Flagstaff, the hardware was relocated to more appropriate space in Denver,

thereby delaying its use. As an interim measure, a high-speed computer and 12-TB disk array was maintained in Reston to process and store the map images. This task overwhelms common desktop hardware within the project's budget, and excessive time was devoted to repair and repurchasing hardware.

12. Continued to revise existing records in Geolex. Given the many and disparate origins of this Lexicon, revision of existing electronic records inherited from the last-published USGS listing of names (in USGS DDS-6) remains the focus of work. As time permits, critically important stratigraphic information (for example, type localities) is retrieved from the authoritative-published USGS lexicons (for example, Bulletins 896 and 1200) and integrated into Geolex.

13. Scanned the Geologic Name Committee's (GNC) master file of geologic names (~220,000 cards, located in Reston). This collection supplements Geolex, providing many relevant publications for geologic names. Began to organize and process the files for Web service.

14. Continued to scan and process Menlo's collection of GNC cards, which are an invaluable complement to the Reston set.

15. Established cooperation with USGS Library to store and manage the Geologic Name Committee's master card file of geologic names and various legacy files of the Paleontology and Stratigraphy Branch.

16. Began Web site redesign by overhauling the Catalog's Product Description Pages, thereby offering access to the various new image file formats and a better "visual experience" for the user. Redesign of other pages has begun.

Task Two

Geoscience information increasingly is available in digital format. Within an agency, program, or a project, there are standard practices for the preparation and distribution of this information. However, widely accepted standards and (or) guidelines for the format, content, and symbolization of this information do not yet exist. Such standards are critical to the broader acceptance, comprehension, and use of geoscience information by the nonprofessional and professional alike. Under the mandate of the National Geologic Mapping Act, the NGMDB project serves as one mechanism for coordinating and developing the standards and guidelines that are deemed necessary by the U.S. and international geoscience community.

The NGMDB project leads or assists in development of standards and guidelines for digital database and map preparation, publication, and management. This activity is a challenging one that entails a lengthy period of conceptual design, documentation, and test-implementation. For example: (1) a conceptual data model must be shown to be implementable in a commonly available GIS such as Esri's ArcGIS; (2) a data-interchange standard must be demonstrated to be an effective mechanism for integrating (for example, through the NGMDB portal) the many and varied data systems maintained by the State geological surveys, USGS, and others; and (3) a map symbolization standard must be implemented in, for example, PostScript or ArcGIS before it can be used to create a map product. Then, of course, each proposed standard must become widely adopted; otherwise, it is not really a standard. Internationally, the NGMDB participates in venues that help to develop and refine the U.S. standards. These venues also bring our work to the international community, thereby promoting greater standardization with other countries.

The accomplishments listed below address a fundamental NGMDB goal—to propose a "core" set of standards and guidelines for endorsement by the Nation's geological surveys. Throughout the past decade and more, geological surveys have collaborated on geologic map database design, science terminology, and data interchange standards. Progress has been significant and was in part facilitated by long-term technical and funding support by the NGMDB project and by the 16 annual DMT meetings.

Specific accomplishments in 2010 include:

1. Organized and led the fourteenth annual "Digital Mapping Techniques" workshop. Developed the agenda, solicited presentations, and worked to prepare the workshop proceedings. Edited the workshop Proceedings from the previous year's meeting (DMT '09, Morgantown, WV) and completed production of the DMT'08 Proceedings.

2. Continued to collaborate with the USGS Pacific Northwest project to design a database format suitable for digital publication of single, traditional geologic maps. This database design ("NCGMP09") attempts to balance the map-preparation and publication-workflow needs of a mapping project and the long-term, national need to archive standardized geologic map data from many projects (NCGMP, 2010). NCGMP09 is an ArcGeodatabase design supported by example map databases, standard vocabularies, documentation, and prototype tools such as error-checking scripts. In early- to mid-2010, extensive technical sessions were held with geologists and GIS specialists in USGS geologic mapping projects in order to evaluate the design and solicit suggested changes. In this initial phase of development, the focus was limited to the geologic-map preparation requirements of NCGMP-funded projects in the USGS, with the intention to then hold discussion with the State geological surveys in order to further refine the database design. Revisions made to NCGMP09 after its introduction at the DMT'09 meeting were discussed at the DMT'10 meeting, specifically to begin to solicit comment from the State geological surveys.

3. Evaluated the draft set of NGMDB standard terminology lists that were developed in past years for their suitability to support the NGMDB project and NCGMP09. Began evaluating the IUGS CGI-sponsored GeoSciML terminology lists. This is an ongoing process, as these term lists evolve by consensus among various scientists and interest groups.

4. Continued collaboration with Esri on an ArcGIS Geology Data Model compatible with NCGMP09. Discussed feasibility of developing a book in their ArcGIS database design series, focusing on geologic map database design.

5. Coordinated work on the Federal Geographic Data Committee (FGDC) geologic map symbolization Standard. Made minor revisions to the Standard and addressed all user comments, requests for materials, and technical questions.

6. Continued to work with Esri on their implementation of the FGDC standard. Provided technical guidance on science and technical aspects, and on preferred workflows for creating well-symbolized products from legacy maps and new map databases. Worked with Esri on details of adapting their implementation to more directly support the NCGMP09 design. Funded the continuing work by USGS staff to create technical specifications and to evaluate Esri's implementation.

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

8. Served as Chair of FGDC Geologic Data Subcommittee. Managed the Subcommittee's Web site.

9. Served as: (a) U.S. Council Member to IUGS Commission for the Management and Application of Geoscience Information (CGI); (b) U.S. representative to DIMAS, the standards body for the Commission for the Geological Map of the World; and (c) USGS technical representative to the OneGeology project.

Specific accomplishments in 2011 include:

1. Organized and led the fifteenth annual "Digital Mapping Techniques" workshop. Developed the agenda, solicited presentations, and worked to prepare the workshop proceedings. Edited the workshop Proceedings from the previous year's meeting (DMT '10, Sacramento, CA), and completed production of the DMT'09 Proceedings.

2. Continued to collaborate with USGS Pacific Northwest project to design a database format suitable for publication of geologic maps. This database design ("NCGMP09") is a carefully planned balance between the map-preparation and publication-workflow needs of a mapping project and the long-term, national need to archive standardized geologic map data from many projects. NCGMP09 is an ArcGeodatabase design supported by example map databases, standard vocabularies, documentation, and prototype tools such as error-checking scripts. Extensive technical sessions were held with geologists and GIS specialists to evaluate the design and solicit suggested changes. Revisions to the design, and to the documentation and software tools that facilitate its use in ArcGIS, were completed as v. 1.1, released in early 2011. The revision included significant design changes and adapted the GeneralLithology classification developed for the NGMDB Data Portal under Task 3.

3. Continued to evaluate the IUGS CGI-sponsored GeoSciML draft interoperability standard and terminology lists for their suitability to support the NGMDB project and NCGMP09. This is an ongoing process, as these term lists evolve by consensus among various scientists and interest groups.

4. Coordinated work on the FGDC geologic map symbolization Standard. Made minor revisions to the Standard and addressed all user comments, requests for materials, and technical questions.

5. Continued to work with Esri on their implementation of the FGDC standard. Funded the continuing work by SPN-Menlo staff to create technical specs and to evaluate Esri's implementation. Provided technical guidance to Esri on science and technical issues and on preferred workflows for creating well-symbolized products from legacy maps and new map databases. Worked with Esri to adapt their implementation—their newly-released version ("Esri-ncgmp") adopts the NCGMP09 data structure.

6. Gave project presentations at several State geological surveys. Explained details of the project and increased their participation in building various NGMDB standards and databases (for example, Map Catalog, Geolex).

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

8. Served as Chair of FGDC Geologic Data Subcommittee. Managed the Subcommittee's Web site.

9. Served as USGS technical advisor to the OneGeology project.

Task Three

From the NGMDB project's origin in 1995 it has been the generally held vision, by users and colleagues alike, that the National Geologic Map Database would, principally, be a repository of GIS data for geologic maps and related information, managed in a complex system distributed among the USGS and State geological surveys. The system would offer public access to attributed vector and raster geoscience data, and allow users to perform queries online, create derivative maps, and download source and derived map data. Further, all information in the database would retain metadata that clearly indicates its source (that is, who created a particular contact, fault, or delineation of a map unit contained in the database, and how the feature or attributes were later modified by further study).

To realize this vision will require: (1) full commitment and close collaboration among the partners; (2) a flexible and evolving set of standards, guidelines, and data management protocols; (3) a clear understanding of the technical challenges to building such a system; and (4) an adequate source of funding. This task is designed to foster an environment where the distributed database system can be prototyped while these requirements are being addressed by the partners.

This is a long-term effort for which the fully realized form is, at this time, difficult to predict. It is a complex task that depends on data availability, technological evolution, skilled personnel (in high demand and, therefore, in short supply), and the ability for all participants to reach consensus on the approach. Bearing this in mind, the scope and details of this Task have been systematically explored and developed through prototypes. Each prototype addressed aspects of the database design, implementation in GIS software (for example, ArcGIS), standard science terminologies, and software tools designed to facilitate data entry. Each prototype was presented to the participants and the public for comment and guidance. The focus of new prototypes is guided by the comments received.

For example, in fiscal year 2001 (FY01) the NGMDB project 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 of the prototype was to implement the North American Data Model (NADM; *http://ngmdb.usgs.gov/www-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 and GeoSciML (see Task 2).

We then considered plans to improve that system by adding more complex geologic data and software functionality. However, doing so would have required significant new funding at a time when technology and geoscience community ideas on database design were rapidly evolving. Therefore, a more limited approach was pursued in the next prototype, in which draft NGMDB science terminologies, a NADM-based database design, and data-entry tools were devised in order for the project to develop a Data Portal (*http://maps.ngmdb.us/dataviewer/* and see discussion in Soller, 2009). The prototype NGMDB Data Portal was publicly released in June 2009; the prototype offered public access to a simplified view of GIS data held by USGS and the geological surveys of Washington, Oregon, and Idaho. As with previous Task Three prototypes, further development of this Portal that is based on more collaboration with these States, or others, depends on public response.

Status of this task in 2010 was as follows:

1. After developing the NGMDB Data Portal (*http://maps.ngmdb.us/dataviewer/*) sufficiently to make it available at a public Web site, we entered an evaluation phase. Further development of the Portal's interface, and additions to content, were temporarily halted in order to assess public reaction to the site and to solicit expressions of interest or concern from our partners in AASG. Public comment indicated that the Portal has some value as an entry point to the Map Catalog and that the science portrayed in the Portal is well expressed with the Portal's Dynamic Legend. Comments from the AASG were insufficient to indicate whether, if we proceed with further development, there could be a productive effort to integrate this Portal with similar GIS-based Web-mapping sites in the State geological surveys. Comment and guidance will continue to be solicited in order to determine if, or how, this work will proceed. The two most probable actions are these: (a) the Portal will be significantly expanded, with new datasets and interface features, and (or) (b) concepts, software components, and (or) datasets will be used in other NGMDB applications (for example, to improve the Map Catalog's "Geographic Search" function). Given the nature of prototyping a system such as this, under conditions of rapidly changing technologies, it is entirely possible that only action "b" will be taken, and the Portal's technology would be absorbed into other parts of the project. This evaluation also will consider the appropriate role for NGMDB in providing GIS-based map information to the public. The evaluation will principally be based on guidance from USGS and AASG.

2. Esri's "Geology base map" (similar in purpose to the NGDMB Data Portal) also was publicly released this year and became a static entity that remains under evaluation. Scientific guidance and discussions continued with Esri regarding possible collaboration and integration of their portal and NGMDB's portal.

3. Continued discussions with USGS Central Energy Team regarding establishing collaborative computing and Web services in order to conserve funds and bring more map content to their system and the NGMDB. The initial focus, to set up an OGC-compliant Web Service for the newly published database of the Geologic Map of North America (Garrity and Soller, 2009), was successful in linking this map database to the Energy Team's global GIS interface for energy-related maps and information ("EnVision", *http://certmapper.cr.usgs.gov/data/envision/index.html*).

Status of this task in 2011 was as follows:

1. After developing the NGMDB Data Portal in 2010 (*http://maps.ngmdb.us/dataviewer/*) sufficiently to make it available at a public Web site, we entered an evaluation phase. Further development of the Portal's interface, and additions to content, were halted in order to: (a) use project resources for higher priority tasks (nos. 1 and 2); (b) assess public reaction to the site; (c) solicit expressions of interest or concern from our partners in AASG; and (d) determine if certain new, more focused, and better funded projects such as the NSF-funded Geoinformatics (GIN) project, the AASG Geothermal project, and Esri's Geology Community BaseMap might provide this service without necessitating a large investment by the NGMDB. Therefore, the Portal Web site was maintained but not enhanced, and content developed for that site (that is, the GeneralLithology classification) was applied to other NGMDB tasks.

2. Esri's "Geology Community BaseMap" (similar in concept to the NGDMB Data Portal) was significantly enhanced this year, with new content. This work is part of Esri's new initiative to develop such resources for various market sectors. NGMDB personnel provided guidance on content and focus as requested.

3. Continued to collaborate with the USGS Central Energy Team on computing and Web services issues in order to conserve funds and bring more map content to their system and ours. Brought new NGMDB servers into their computing facility.

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Appendix. List of progress reports on the National Geologic Map Database, and Proceedings of the Digital Mapping Techniques workshops.

Soller, D.R., ed., 2012, Digital Mapping Techniques '10—Workshop Proceedings: U.S. Geological Survey Open-File Report 2012–1171, 170 p., *http://pubs.usgs.gov/of/2012/1171/*.

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Soller, D.R., ed., 2009, Digital Mapping Techniques '08—Workshop Proceedings: U.S. Geological Survey Open-File Report 2009-1298, 216 p., *http://pubs.usgs.gov/of/2009/1298/*.

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

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