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Digital Mapping Techniques '99— Workshop Proceedings

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and the
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Hosted by the
Wisconsin Geological and Natural History Survey

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CONTENTS

CONTENTS

CONTENTS

Introduction

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The *Digital Mapping Techniques '99* (DMT'99) workshop was attended by 91 technical experts from 42 agencies, universities, and private companies, including representatives from 30 state geological surveys (see Appendix A). This workshop was similar in nature to the first two meetings, held in June, 1997, in Lawrence, Kansas (Soller, 1997), and in May, 1998, in Champaign, Illinois (Soller, 1998a). This year's meeting was hosted by the Wisconsin Geological and Natural History Survey, from May 19 to 22, 1999, on the University of Wisconsin campus in Madison. As in the previous meetings, the objective was to foster informal discussion and exchange of technical information. When, based on discussions at the workshop, an attendee adopts or modifies a newly learned technique, the workshop clearly has met that objective. Evidence of learning and cooperation among participating agencies continued to be a highlight of the DMT workshops (see example in Soller, 1998b, and various papers in this volume).

The meeting's general goal was to help move the state geological surveys and the USGS toward development of more cost-effective, flexible, and useful systems for digital mapping and geographic information systems (GIS) analysis. Through oral and poster presentations and special discussion sessions, emphasis was given to: 1) methods for creating and publishing map products (here, "publishing" includes Web-based release); 2) continued development of the National Geologic Map Database; and 3) progress toward building a standard geologic map data model. Especially to support the interest in map preparation and publication, five representatives of the GIS hardware and software vendor community were invited to participate.

The three annual DMT workshops were coordinated by the AASG/USGS Data Capture Working Group, which was formed in August, 1996, to support the Association of American State Geologists and the USGS in their effort to build a National Geologic Map Database (see Soller and Berg, this volume, and <http://ncgmp.usgs.gov/ngmdbproject/standards/datacapt/datacaptureWG.html>). The Working Group was formed because increased production efficiencies, standardization, and quality of digital map products were needed to help the Database, and the State and Federal geological surveys, provide more high-quality digital maps to the public.

ACKNOWLEDGMENTS

I thank the Wisconsin Geological and Natural History Survey (WGNHS), and their Chief and State Geologist, James Robertson, for hosting this very productive and enjoyable meeting. I especially thank Mindy James (WGNHS), who coordinated the meeting, provided excellent support for the attendees, and maintained the meeting's web site (see Appendix B). Her expertise and sense of humor are greatly appreciated. Thanks also to Mike Czechanski, Chip Hankley, Rilla Hinkes, Marcia Jesperson, Deb Patterson, Kathy Roushar, and Kathie Zwettler (all WGNHS) for helping with the meeting logistics, Phil O'Leary (U. Wisconsin) for allowing us to use the meeting facilities, and Dave Carlson (USGS) for setting up the online registration. I also note with gratitude the contributions of the following individuals: Tom Berg (Chair, AASG Digital Geologic Mapping Committee) for his help in conducting the meeting and for his continued support of AASG/USGS efforts to collaborate on the National Geologic Map Database; the members of the Data Capture Working Group (Warren Anderson, Kentucky Geological Survey; Rick Berquist and Elizabeth Campbell, Virginia Division of Mines and Geology; Rob Krumm and Barb Stiff, Illinois State Geological Survey; Scott McColloch, West Virginia Geological and Economic Survey; Gina Ross, Kansas Geological Survey; Dave Wagner, California Division of Mines and Geology; and Tom Whitfield, Pennsylvania Geological Survey) for advice in planning the workshop's content and the suggestions to authors; and Adam Davis (USGS) for help with Appendix C. Finally, I thank all attendees for their participation; their enthusiasm and expertise were the primary reasons for the meeting's success.

PRESENTATIONS

The workshop included 32 oral presentations. Nearly all are supported by a short paper contained in these Proceedings. Some presentations were coordinated with Discussion Sessions, described below. The papers represent approaches that currently meet some or all needs for digital mapping at the respective agency. There is not, of course, a single "solution" or approach to digital mapping that will work for each agency or for each program or group within an agency — personnel and funding levels, and the schedule, data format, and manner in which we must deliver our information to the public require that each agency design their own approach. However, the value of this workshop, and other forums like it, is through their role in helping to design or refine these agency-specific approaches to digital mapping and to find approaches used by other agencies that are applicable. In other words, communication helps us to avoid "reinventing the wheel."

Most presentations ranged across a number of issues, so I make little attempt to organize the papers by topic. With my apologies to authors whose work I may not adequately describe, I provide here a brief description of each paper. For the sake of brevity, the lead or presenting author only is listed. Further information about the software and hardware referred to below and elsewhere in these Proceedings is provided in Appendix C.

1. Gregory J. Allord (U.S. Geological Survey)—development of the new *National Atlas of the United States of America*, a government-wide effort to deliver map information to the public.

2. T. Wayne Furr (Oklahoma Geological Survey)—evolution of digital cartographic methods at the Oklahoma Geological Survey.

3. Todd Fitzgibbon (U.S. Geological Survey)—an approach for creating, reviewing, and releasing digital geologic map products (paper not supplied).

4. Diane E. Lane (U.S. Geological Survey)—methods for digital geologic map production and database development in the Central Publications Group.

5. Susan Muleme (Avenza Software Marketing Inc.)—introduction to MaPublisher plugin for Adobe Illustrator.

6. Alberto Berry (Hewlett-Packard Company)—current and future technologies for large format DesignJet plotters.

7. David McCraw (New Mexico Bureau of Mines and Mineral Resources)—challenges to integrating digital topographic bases with geologic maps.

8. Robert Lemen (U.S. Geological Survey)—creation of base map products in the USGS National Mapping Program.

9. David R. Soller (U.S. Geological Survey)—progress report on the National Geologic Map Database.

10. David R. Soller (U.S. Geological Survey)—special discussion session: proposed guidelines for inclusion of digital map products in the National Geologic Map Database.

11. Rick Berquist (Virginia Division of Mineral Resources)—authorship and citation of digital geologic maps and spatial data.

12. Peter Schweitzer (U.S. Geological Survey)—plain-language resources for metadata creators and reviewers.

13. Mike Price (Environmental Systems Research Institute, Inc.)—introduction to ArcInfo 8: New GIS technology from ESRI.

14. Skip Pack (Dynamic Graphics, Inc.)—introduction to EarthVision: extracting information from 3D geologic models.

15. Gary D. Latzke (U.S. Geological Survey)—production methods and products in the series *Ground Water Atlas of the United States.*

16. Xin-Yue Yang (Kentucky Geological Survey)—an ArcView tool for automating selection of map data from a geologic map database.

17. Data Model Steering Committee—special discussion session: development of a draft standard geologic map data model and the Steering Committee.

18. Stephen M. Richard (Arizona Geological Survey)—data model concepts, and thoughts on implementing parts of the draft standard geologic map data model.

19. Donald L. Gautier (U.S. Geological Survey)—applying the draft standard data model to single geologic map products.

20. Boyan Brodaric (Geological Survey of Canada)—using the draft standard data model as the basis for a web-based geoscience library prototype.

21. Ronald R. Wahl (U.S. Geological Survey)—problems in representing spatial objects with typical GIS software.

22. Eric Boisvert (Geological Survey of Canada)—a software tool for attributing geologic maps in the draft standard data model format.

23. David R. Collins (Kansas Geological Survey)—development of the Kansas Geologic Names Database, and possible links to the draft standard data model.

24. Brian Berdusco (Ontario Geological Survey)—functional analysis of GIS, development of digital mapping methods, and application to compilation of a geologic map.

25. Warren H. Anderson (Kentucky Geological Survey)—creating a statewide digital geologic map database.

26. Gregory J. Walsh (U.S. Geological Survey)—using GPS and hand-held computers for geologic mapping.

27. Harold W. Baker (Missouri Geological Survey)—applying ArcView to geologic map compilation and production.

28. David R. Bedford (U.S. Geological Survey)—creating a geologic map and digital photolibrary for management applications.

29. Frank Ganley (Alaska Division of Geological and Geophysical Surveys)—review of agency mapping program, and update of progress in implementing digital mapping.

30. Nick Tew (Geological Survey of Alabama)—digital geologic map production, and geologic map applications to groundwater vulnerability studies.

31. Steve Fryer (National Park Service)—the geologic resources inventory program.

32. Jeffrey M. Hyatt (Intergraph Corp.)—overview of cartography and GIS products from Intergraph (paper not supplied).

POSTERS

More than 15 posters were exhibited throughout the workshop. These posters provided an excellent focus for technical discussions and support for oral presentations. Most are documented with a paper in these Proceedings, following the oral presentations.

DISCUSSION SESSIONS

To provide the opportunity to consider a topic in some detail, special discussion sessions were held. These addressed: 1) proposed guidelines for inclusion of digital map products in the National Geologic Map Database; 2) progress toward development of a draft standard geologic map data model; and 3) a general discussion of ideas presented during the meeting. Discussion session #1 led to revisions to the draft proposal (Soller, Duncan, Ellis, Giglierano, and Hess, this volume) and the recommendation to submit the guidelines to management for consideration. Session #2 provided increased understanding of the new process being used to promote development of the standard data model, and session #3 provided recommendations for new features to add to future DMT meetings.

THE NEXT DMT WORKSHOP

At discussion session #3, it was decided that a fourth annual DMT meeting would be held, next year. While planning for that event, the Data Capture Working Group will carefully consider the recommendations offered by DMT'99 attendees.

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

Soller, D.R., 1998b, Introduction, in: D.R. Soller, ed., Digital Mapping Techniques '98—Workshop Proceedings: U.S. Geological Survey Open-File Report 98-487, p. 1-3, <http://pubs.usgs.gov/openfile/of98-487/intro.html>.

The National Atlas of the United States of America

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A new National Atlas was authorized in 1997 to update the original Atlas published in 1970. The first National Atlas was generally found in reference collections of libraries as well as being used by educators and government organizations. This edition was a 400 page, 12 pound printed book with 765 maps that took 7 years to produce. The $100 price was a deterrent for purchase for home use. This new National Atlas is intended to reach audiences not typically addressed by U. S. Government programs and products. Initial Atlas design efforts concentrated on identifying customers, determining their expectations, and using this market research to refine product definitions. The new National Atlas is designed for individuals who own powerful home computers.

The National Atlas of the United States of America™ (http://www.nationalatlas.gov) will include four distinct products: high-quality small-scale maps; authoritative, documented national geospatial and geostatistical data sets; easy-to-use web-based software for data display, query and custom information; and hot links to other sites on the WWW for up-to-date, real-time, and regional data. The U.S. Geological Survey, the lead agency in this Government-wide effort, is also developing partnerships to make a product that is responsive to the needs of secondary markets like education, businesses, and libraries. The National Atlas will realize these goals for delivery of information through the WWW and on CD-ROM products through a combination of Government support as well as Cooperative Research and Development Agreements signed with one or more private businesses.

Geologic Mapping at the Oklahoma Geological Survey: The Move From Traditional to Digital Cartography

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HISTORY

The Oklahoma Geological Survey (OGS) has maintained a strong commitment to mapping the geology and natural resources of the State of Oklahoma; a commitment that began before statehood with its predecessor organization, the Oklahoma Territorial Geological Survey. In 1904, before becoming the first State Geologist, Dr. Charles N. Gould, prepared a preliminary geologic map of the Oklahoma Territory. Three years later, Gould contributed to the development of the enabling act for the creation of the state geological survey. When comparing length of service to other state geological surveys OGS may be considered an infant. However, OGS claims the distinction of being the only state geological survey in the nation to have been created under a directive of the constitution of a newly formed state.

The objectives and duties of the new survey were defined by Oklahoma's First Legislature. Senate Bill No. 75 provided for a study of the geological formations of the State with special reference to its mineral deposits, including the preparation and publication of reports with maps. The reports are to provide both general and detailed descriptions of the State's geological resources.

The first full-color geologic map of Oklahoma, compiled by Hugh D. Miser of the U.S. Geological Survey (USGS), was released in 1926. After 20 years of use, the map not only was outdated it was out of print as well. In 1947, Miser returned to Norman to supervise revision of the 1926 map. Miser and 10 additional authors are given credit for the geologic map of Oklahoma that was released in 1954 (Ham, 1983, p. 7). Forty-five years later the map is still in use, but in need of major revisions. Mapping and other kinds of field studies have continued with the completion of 145 Bulletins, 100 Circulars, 35 Mineral Reports, 31 Guidebooks, 5 Educational Publications, 35 Geologic Maps, 9 Hydrologic Atlases, 65 Special Publications, and 45 Open-File Reports.

MAPPING PROGRAMS

Currently, OGS is conducting four kinds of geological mapping programs: county, resource, 7.5-minute quadrangle, and 1:100,000 digital compilation. The purpose of these programs is to provide a better understanding of the State's geological history and resources. The knowledge gained will enable public policy-makers and industry to safely and wisely utilize Oklahoma's geological resources.

For more than 70 years, county mapping has been the cornerstone of geological investigations at OGS. Kay County, located in north-central Oklahoma is the most recent to be mapped. Currently, geologic investigations are underway in the western part of Osage County. Traditionally, investigations in the county geological mapping program have been produced in the Bulletin and Circular Series with maps at a scale of 1:63,360.

Recent resource mapping in Oklahoma has focused on the coal reserves and environmental problems associated with past mining, including poor reclamation techniques. The principal user of the OGS coal-resource maps is industry. Several mines in the State have been developed based on information provided from these studies.

Beginning in 1985, a program to map the northern part of the Ouachita Mountains fold-and-thrust belt and the southern part of the Arkoma foreland basin was conducted. Designed to support natural-gas exploration and coal development, and to reduce associated environmental hazards, 22 geological-quadrangle maps were produced. In 1998, OGS shifted new mapping efforts to the northern Oklahoma City metropolitan area. Twelve 7.5-minute quadrangles were selected, with completion expected by July of the year 2000. The purpose of this mapping is to provide area planners with detailed geologic maps that will enable them to make informed decisions with regard to aquifer protection, resource development, and highway construction.

In late 1994, the Oklahoma Geologic Mapping Advisory Committee (OGMAC) recommended that OGS prepare a series of geologic maps at a scale of 1:100,000 for the entire State using digital technology. The purpose of the maps is to provide a Geographical Information System (GIS) geologic data base for industry, public officials, area planners, and other interested parties. In addition, this series will provide the foundation for a new 1:500,000-scale geologic map of the State. Maps in this series are compilations of geologic investigations from various sources, with field checks used to fill gaps found in prior investigations and improve on earlier mapping efforts.

Partial funding for the OGS geological mapping activities has been provided under two separate grants. From 1985 to 1993, mapping was funded through the COGEOMAP Program, an agreement between the OGS, the Arkansas Geological Commission, and the USGS. Since 1994, geologic mapping has been funded through the STATEMAP component of the National Cooperative Geologic Mapping Program.

1:100,000-SCALE DIGITAL COMPILATION

In 1996–1997, two 30 x 60 minute quadrangles in western Oklahoma were compiled to test OGS compilation efforts and digital capabilities. The Watonga and Foss Reservoir quadrangles (figure 1) were chosen because the bedrock geology, consisting mostly of gently dipping Permian redbeds, is relatively simple and well known. The highly dissected terrain, however, results in complex cartographic patterns.

In September 1996, OGMAC recommended that OGS concentrate on the Oklahoma Panhandle. The mapping will complement ongoing studies in the area conducted by the Oklahoma Water Resources Board and Water Resources Division of the USGS. Investigations by each agency will provide a better understanding of environmental issues associated with an increasing transportation infrastructure, numbers of feed lots, and meat-processing plants. OGS geologists started compiling the geology in the westernmost quadrangle in 1997. The digitizing, GIS-attributing, and cartographic production has essentially been completed on the Boise City Quadrangle. Completion of the Guymon and Beaver quadrangles is expected by the end of June 1999 (figure 1).

Methods Used

I. OGS Geologist

1. Conducts library research and compiles all existing modern geologic contacts on a 1:100,000 green-line base (Note: A green-line base is a frosted-film sheet with the base map printed in green).
2. Supplements compilation and resolves different geologic maps with air-photo interpretation and/or reconnaissance field checking.
3. After compilation, a paper print is made and the geologist colors the formations, checking for gaps or open formation contacts.
4. An explanation, area of investigation map, and other necessary information is prepared.
5. This package of information is turned over to the cartographer for processing.

II. OGS Cartographic Staff

6. Using scribing, the cartographer makes a line-work separation of the geologic contacts from the base map.
7. Prepares a geologic color-selection guide
8. Prepares a map layout guide.
9. Makes a clear film or paper photo print of the geologic line work.
10. The photo print, color selection guide, and map layout guide is turned over to the GIS specialist. Currently, the GIS processing is under contract to an individual at Oklahoma State University (OSU).

III. GIS Specialist

11. The specialist scans the 1:100,000-scale photo positive of the geologic map sheet at 400 dots per inch on an ANAtec 3640 Eagle optical scanner.
12. The scanned (raster) image is converted to vector polygons utilizing LtPlus raster-to-vector conversion software on a SUN SPARC workstation.
13. A plot of the digital vector data is made at 1:100,000 scale on an HP650C plotter and visually compared with the original map compilation to ensure completeness and precision of scanning and data conversion.
14. Within LtPlus, polygon topology is created, each polygon is attributed, and a series of quality-control checks is performed with software macros (programs).
15. The digital data is then exported from LtPlus in standard USGS DLG-3 format and imported into Arc/Info version 7.0.3.
16. A plotting routine is written and executed in Arc Macro Language program to utilize the digital geology polygons as part of a 1:100,000-scale geologic map.
17. Base map layers, a title, explanation, text, and index maps are added to complete the map layout.
18. On request, the completed map data sets will be made available to the public in one of the following formats: (a) Arc/Info export format (.e00), (b) ArcView shapefiles, or (c) USGS DLG-3 format for access through

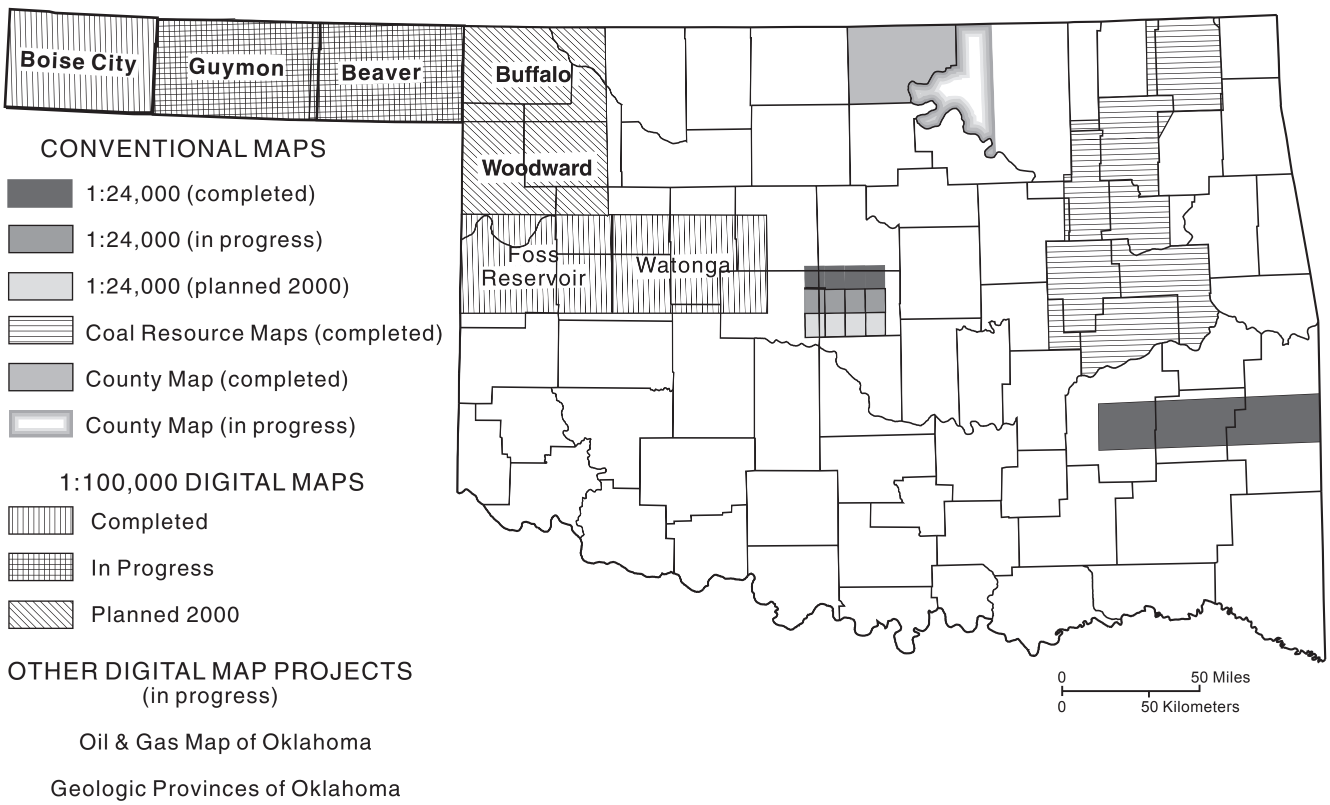

Figure 1. Index to 1:100,000-scale geologic maps in Oklahoma.

the World Wide Web via a Web browser or by file transfer protocol (ftp) (Furr, Gregory, and Suneson, 1998). Note: At the present time, the exact procedure, file format, and method of distribution described in step 18 have not been determined.

GIS vs. Published Maps

In addition to the GIS format, Dr. Charles J. Mankin, Director of OGS, expressed the need to publish each geologic quadrangle in full color for release in our Geologic Map Series. Having two different types of digital products presented a different set of problems. The biggest complaint expressed by reviewers of printed GIS maps was graphic presentation. They expected to see standard geologic colors, lettering, and other symbols. Unfortunately, graphic presentation has never been a strong point in most GIS programs. Another problem was converting the GIS files to a publishable format. A GIS is an analysis tool designed to evaluate a range of possible scenarios. By evaluating different possibilities, a course of action can be considered before irrevocable mistakes are made in the landscape itself (Burrough, 1986, p. 7). In other words, a GIS was never intended to be the computer toolbox for designing, drafting, and printing maps in the traditional way. As a result, from the GIS file format, it is difficult to provide to the printing industry a digital file that is compatible with the industry's graphic-output devices.

These problems and others have been addressed by agencies that have tried to use a GIS as a publishing tool. In checking with other state geological surveys, private cartographic firms, pre-press, and printing companies, the answers are not entirely clear. Many agencies use Macintosh computers, others use PCs with a variety of operating systems, and others use UNIX-based workstations. A multitude of software was also found to be in use. Some were using one of several GIS programs, some were using CAD programs, while others were using a variety of graphic software programs. The pre-press and printing firms were not familiar with GIS file formats, but preferred to use files created in Adobe Illustrator.

The OGS Cartographic Section's computer setup consists of Pentium II PCs with Windows NT operating systems. Software includes Microsoft Office, ArcView 3.0a, and Adobe Illustrator 7.0.1. One problem that had to be addressed was how to import GIS files to Illustrator while maintaining the GIS attributing. For this operation, third-party software was needed to bridge the gap between ArcView shapefiles and Adobe Illustrator. The third-party software chosen was MAPublisher from Avenza Software. MAPublisher is a cartographic-geographic information system for integrating GIS files directly into Adobe Illustrator while maintaining the GIS attributing. The plug-in filters allow the cartographer to consider map projections, scale, color, and necessary cartographic operations, while maintaining the GIS functionality. The completed map project can be saved in one of the many formats used by the pre-press and printing industry. In addition, map layers can be exported as shapefiles for use in a GIS.

Adjustments to OGS Methods

As a result of the lessons learned from the Watonga and Foss Reservoir quadrangles and the availability of new software, several changes in the method of map production were made as work progressed on the Boise City quadrangle. Steps 1 through 16 described previously remained the same. One change being considered for future projects is dropping the printed green-line base in favor of a clear-film base map with a frosted-mylar overlay. The expected goal is that the geologist carefully drafting the geologic contacts will eliminate the need for the cartographer to make a line-work separation and the expense of a photographic positive.

Adjusted Methods

To recap step 16 from before: A plotting routine is written and executed in Arc Macro Language program to utilize the digital geology polygons as part of a 1:100,000-scale geologic map.

17. The geologic-polygon and base map image file layers are placed on the OSU (Department of Plant and Soil Sciences) file server in ArcView shapefile format.

18. The cartographer transfers the files to the OGS computer network using standard file transfer protocol (ftp)

19. The ArcView shapefiles are moved into Adobe Illustrator using MAPublisher's import filter.

20. Using Illustrator, the cartographer performs the necessary cartographic work to bring the map to OGS standards by adding the title, explanation, index map(s), geologic letter symbols, and colors.

21. File formats for printing the maps are created and sent to the printer.

22. The geologic map data base is exported in ArcView shapefile format for use in GIS applications.

23. On request, the completed map data sets will be made available to the public in one of the following formats: (a) Arc/Info export format (.e00), (b) ArcView shapefiles, or (c) USGS DLG-3 format for access through the World Wide Web via a Web browser or by file transfer protocol (ftp). Note: At the present time, the exact procedure, file format, and method of distribution described in step 23 have not been determined.

SUMMARY

The OGS Cartographic Section started using computers to produce figures and illustrations for publications about five years ago. Geologic maps in the 1:100,000-scale series are the Survey's first attempt at using GIS concepts and graphics software jointly to produce maps for printing. The methods used provide a workable solution that can be adopted by agencies with similar production needs. Cartographic production of the Boise City map was approximately three times faster than traditional drafting methods. The need for cartographic materials, such as scribe-sheets, peel-coats, type-overlays, and other traditional materials, as well as the use of supporting laboratories is virtually eliminated. The various geological mapping programs at OGS are expected to expand as experience is gained using GIS in combination with digital cartography. To accomplish overall goals, methods will be adjusted and production speed is expected to increase. With materials and support for traditional cartographic methods diminishing the need to totally convert to digital production for all maps at the OGS is rapidly approaching.

Future mapping will include additional 7.5-minute quadrangles in the Oklahoma City area and 1:100,000-scale quadrangle(s) in western Oklahoma. Additional projects being considered for production in both digital and publishable formats are the Oil and Gas Map of Oklahoma at a scale of 1:500,000, the Geologic Province Map of Oklahoma at a scale of 1:750,000, and the expanded revision of Educational Publication 1. In addition to the geologic mapping programs, an inventory of all geologic maps published by OGS is being compiled and entered into the National Geologic Map Database <http://ngmdb.usgs.gov>. As a state agency, the Oklahoma Geological Survey has made a commitment to meet the needs of the State's citizens by providing high-quality printed maps, as well as GIS data bases of the State's geological resources.

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Digital Geologic Map Production and Database Development in the Central Publications Group of the Geologic Division, U.S. Geological Survey

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INTRODUCTION

During the transition from manual to digital cartographic preparation of thematic maps over the past several years the Central Publications Group (CPG) of the Geologic Division, U.S. Geological Survey (USGS), has produced maps from a variety of compilation materials submitted by authors: conventional drafting on film; maps digitized by authors or contractors in GSMAP or, more recently, GSMCAD (both programs available at <http://ncgmp.cr.usgs.gov/ncgmp/gsmcad/> or <http://greenwood.cr.usgs.gov/maps/software.html>; for a description, see Williams, 1997); maps digitized by authors or contractors in Arc/Info; maps drafted by authors in a graphics program, such as Adobe Illustrator; maps generated by programs widely used by USGS geophysicists; and hybrid maps using more than one of these approaches. Some authors produce final cartographic layouts for their maps themselves, and others rely on CPG for final production. Along the way we have encountered problems with digital production from these various sources but have found solutions to the extent that most of the maps currently in production are wholly digital in the sense that the map is output from a digital file.

In addition to the challenge of producing maps from such a variety of compilation materials, we need to produce maps for release online, for plotting on demand on a high-resolution plotter, and for printing on a press; we also need to work with authors to place digital databases and metadata online. Our poster presentation for this workshop outlines some procedures for producing maps that work for us in our publications environment.

PRODUCTION PROCEDURES

We import digital files for geologic maps into Adobe Illustrator via Avenza MAPublisher and use the powerful graphics capabilities of Illustrator to compose the final layout of a map sheet rather than trying to do so in a GIS (see fig. 1). Composing the map sheet in this way lets us speed up production dramatically while retaining the traditional look of a USGS map.

Step 1. Digitize the Map

We obtain digital files from the author or we pay a contractor to do the work. The geologic maps referenced here and in our poster display were digitized in a CAD program or scanned and processed into Arc/Info coverages.

Before contracting for the digitizing we sometimes choose first to have a cartographic contractor scribe very complex conventionally drafted linework. The contractor scribes one sheet of color boundaries and one or two (depending on complexity) other sheets of lines (such as faults, folds, or caldera boundaries), using a uniform line weight of 0.006 inches and omitting line decorations and point symbols. In some cases we have the contractor ink the map unit symbols on an overlay. We then have clear-film positives made from the scribes and furnish these materials to the digitizing contractor for scanning.

If the linework is not too complex, inked compilations on film are scanned directly. Whether separates are scribed or the original compilation is scanned, we ask the author to make color-coded line and symbol guides to help the contractor accurately attribute polygons, lines, and point symbols. Point symbols on overlays or on the original compilation on film are either (1) digitized by hand or (2) scanned and then used on-screen as a guide for digitizing point symbols in a graphics program. In some cases we provide the digitizing contractor with scans of the

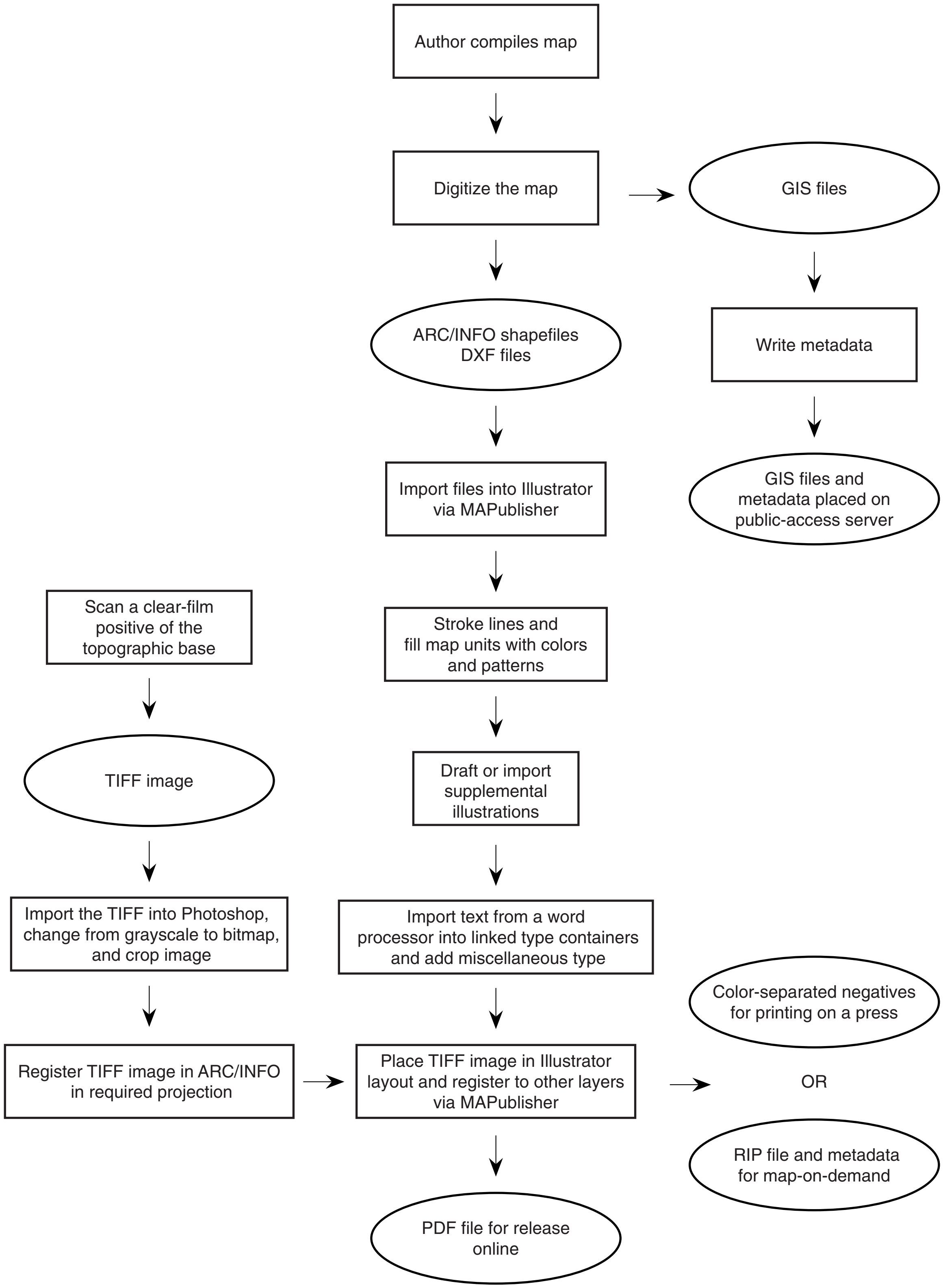

Figure 1. Chart showing basic procedure for digital map production and database development in the Central Publications Group of the Geologic Division, U.S. Geological Survey

topographic base, especially if needed to digitize open-water boundaries.

In contracting for digitizing, we provide standards for accuracy and for coverage attributing. In order to meet our need for both a digital database and usable graphics files, we request two files to represent point symbols. One is an attributed Arc/Info point coverage, and the other is a line coverage that graphically represents the point symbols. Symbols such as the bar and ball on faults or displacement arrows on folds are represented as points (on the line) and attributed accordingly. In other words, we do not want such symbols to be evenly spaced along a line as a decoration such as sawteeth would be, but to be placed exactly where the author placed them.

Step 2. Import Files into Graphics Program via MAPublisher

Avenza MAPublisher 3.0 is a suite of plug-in filters for Adobe Illustrator and Macromedia Freehand that allow these formats to be imported with all attributes intact: Arc/Info generate, ArcView shapefiles, DXF, MapInfo mid/mif, DLG, and SDTS. For ArcView shapefiles, keeping the map attribution intact means that like-attributed features can be selected as a group via MAPublisher in order to adjust the graphic portrayal of that feature. For example, lines that were attributed as solid contacts can be selected as a group in the graphics program, and lines that were attributed as dashed or dotted contacts can be selected as a group and assigned the proper line weight and length of dash. Similarly, the polygons of a map unit can be selected as a group in order to assign colors and patterns. For DXF files exported from a CAD program such as GSMCAD, like-attributed features are imported into their own layers in the graphics program.

For maps digitized in a CAD program, DXF files import properly for polygons, lines, point symbols, and text. For maps from Arc/Info, we import shapefiles for the polygons and lines but use DXF files for the text and for graphical representations of point symbols. In CPG we have worked most extensively with ArcView shapefiles and DXF files. In importing a set of files for a map, it is important not to move the objects imported into Illustrator via MAPublisher until all files have been imported in proper registration.

Step 3. Compose Map Sheet Layout in Graphics Program

Once the digital files for the map have been imported, the line elements of the geologic map itself are stroked (assigned a line type and weight) and polygons, text, and some point symbols are filled with colors and (or) patterns. To select all polygons for one map unit or all instances of a concealed contact, for example, we select all art on one layer in Illustrator or we use the "select by attribute" function of the MAPublisher filter. Which approach we use depends on whether the imported elements were DXF files or ArcView shapefiles.

Cross sections and other supplemental illustrations may be digitized in a CAD program or in Arc/Info, or they may be drafted in a graphics program. GIS files for these illustrations may be imported into the graphics program in the same manner as the map itself. We generally import these into their own Illustrator document to keep the working file size small and adjust lines and colors as we do on the map itself. Layers for these supplemental illustrations can be preserved by checking "paste remembers layers" in Illustrator when copy-pasting the illustration into the layout. However, you will not be able to use the "select by attribute" function of MAPublisher to edit an illustration that is no longer in the Illustrator document into which it was imported.

In choosing colors for a map, we consider whether the map will be printed on a press or only on a plotter. In both cases we follow USGS standards for assigning colors by age and rock type. We choose colors from standard sheets of printed process colors for maps that will be printed on a printing press, but we use a plotted version of the color chart to refine color choices for maps that will be printed only on a plotter. Since plotters differ in their output, we use color charts printed on the same kind of plotter as that used to print maps in the maps-on-demand series for sale to the public.

Using Illustrator, everything that can be done in the nondigital production of a map can be duplicated, including adding patterns to color-filled polygons. We have available in digital form many of the patterns traditionally used on USGS thematic maps. To apply the patterns, we create a separate layer in Illustrator for each map unit to be patterned. We select the polygons for each of these map units and copy them to the new layer, then fill them with the pattern. The polygons on this layer should have no stroke, only the pattern fill. The polygons that are filled with the background color also have no stroke, only the color fill, and should be the bottommost layer in the layers palette in Illustrator. The next lowest layer would be topography, if present, and the layers of polygons filled with patterns should be above the topography. We have found that this order is suited to both printing on a press and on a plotter.

The rest of the map sheet layout is generally composed in the Illustrator document into which the map was originally imported. A typical USGS map includes a correlation of map units, a description of map units, discussion, references, and supplementary illustrations or photographs. Any cross sections or other illustrations drafted in Illustrator or available in other formats (such as EPS or TIFF) are copy-pasted or placed in the Illustrator layout, and text is imported from a word processor (such as MS Word) into linked type containers. Special characters (such as em dashes and degree symbols) are usually preserved, but formatting such as hanging indents and font selections is not—this formatting is done in Illustrator. The addition of bar scales, titles, headnotes, figure captions, and so on completes the layout except for the topographic base.

Step 4. Add a Topographic Base

If a satisfactory vector base (digital line graph) is not available, a scale-stable positive of the base can be scanned and saved as a grayscale (8-bit) TIFF image. We can open the TIFF image in Adobe Photoshop, adjust threshold levels to preserve detail, change the mode from grayscale (8 bit) to bit map (1 bit), and crop the image as needed. We can then register the TIFF image in Arc/Info in a projection that matches the digital coverages for the map, place the TIFF image on its own layer in the Illustrator layout, and use MAPublisher's "register image" filter to reference and scale the image. This new layer is placed directly above all of the color-filled polygons but below any layers of pattern-filled polygons.

In printing geologic maps on a press, we have customarily screened topographic base maps to 30–40 percent black. However, output from a plotter may be more satisfactory if the topographic base layer is screened to 50–60 percent black and if color fills of map units (except for units that occupy only small areas) are no more than 40 percent cyan or magenta (higher percentages of yellow may be used). A base layer screened to a percentage of black that is less than the percentages of the underlying cyan or magenta in larger map areas appears to block out the underlying color rather than to overprint it (for example a 30-percent black topographic base will appear to block out the color of a map unit that is 40 percent magenta).

Step 5. Output the Map Sheet

We have several ways of outputting a digital map. (1) Print on paper at a printing plant. This approach entails the expense of making color-separated negatives from the digital file and then printing and storing the maps. (2) Plot a copy as needed. Plotting on demand eliminates the need to make color-separated negatives and to store the printed maps. However, each on-demand RIP (acronym for Raster Image Processor) file must be archived on a CD-ROM. (3) Convert the digital file to a PDF file and release it online (maximum page size in the newly released Adobe Acrobat 4.0 is 200 x 200 inches).

For maps printed on a press, we currently use a service bureau to output color-separated negatives from our digital files or we give the digital files directly to the printing contractor. In the latter case the printing contractor is responsible for obtaining color-separated negatives from the files we provide. Two examples of maps output in this way for printing are Geologic Investigations Series I–2627 (Day and others, 1998) and I–2630 (O'Neill, 1998).

In CPG we are producing more and more maps that will be "printed" only on a plotter. We export the Illustrator file as an EPS and use Onyx PosterShop Client Server, v. 4.5, to make a RIP file. We provide the USGS Branch of Information Services with the input file (usually the Illustrator file), the RIP file, a README file, and metadata together on a CD-ROM. When a customer orders a map-on-demand product, the RIP file is then plotted on heavy coated paper on an HP Design Jet 3000 CP plotter using UV-resistant inks. Three examples of maps output in this way for the map-on-demand system are Geologic Investigations Series I–2652 (Winkler and others, 1999), I–2656 (Lidke, 1998), and I–2667 (O'Sullivan, 1998). Metadata and information about ordering these maps are available at <http://rmmcweb.cr.usgs.gov/public/mod/>.

Whether we print the map on a press or on a plotter, we now convert the Illustrator file to a PDF file and place it on a public-access server as a complement to the hard-copy map. Some examples of maps output as PDF files are Geologic Investigations Series I–2627 (Day and others, 1998), I–2630 (O'Neill, 1998), I–2631 (O'Neill and Nutt, 1998), I–2652 (Winkler and others, 1999), I–2656 (Lidke, 1998), and I–2667 (O'Sullivan, 1998). The PDF files for all these maps may be accessed through <http://greenwood.cr.usgs.gov/maps/maps.html>.

DEVELOPING AND SERVING A GIS DIGITAL DATABASE FOR THE MAP

We have started placing GIS digital files and metadata in support of the printed or plotted map on a public-access server. A README file describes the available files, and metadata written to the Content Standards for Digital Geospatial Metadata published by the Federal Geographic Data Committee (FGDC) give keywords and detailed information about the scope of the mapping project, the coverages (including descriptions of entities and attributes), the production process, and contacts for further information. One example (Skipp and others, in press) may be accessed at <http://greenwood.cr.usgs.gov/pub/I-maps/I-2634/>.

We carefully review the files provided by the contractor to ensure that all digitizing and attributing errors are corrected in the GIS before placing the GIS files online and importing the files into the Illustrator layout. Even if a printed or plotted map is available, the database may display some elements differently than shown on the hard copy. Therefore, we explain the features of the database as thoroughly as possible in the metadata, pointing out any differences that might be critical to the user.

CONCLUSIONS

The advantages we see in this method of map production are timeliness, ease of distribution, and adaptability of the digital files for different modes of output. Depending on the complexity, composing a map sheet in this way takes only a few days to a week or so once all the elements of the map sheet are in digital form. The completely digital format makes minor revision and reissue of the map quick and easy. Maps produced in this way can be output readily in the cost-effective maps-on-demand system and can be released online.

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Avenza's MAPublisher

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ABSTRACT

Avenza Software Inc., the developers of MAPublisher, is a small company located in Burlington, Ontario. MAPublisher is a suite of Plug-Ins and Xtras for Adobe Illustrator and Macromedia FreeHand. MAPublisher adds GIS capabilities to these two graphics applications. It adds graphics capabilities that are unavailable with a typical GIS. MAPublisher is used by government agencies, educational institutions, and businesses worldwide to create publication quality mapping products from GIS data sources.

AVENZA

The founder of Avenza was hired by the graphics department of a major company to make maps. He quickly realized that he was spending hours completing work that was already available. Why scan and screen digitize endless sheets of paper maps when accurate and georeferenced vectors were readily available? Why spend hours adding database attributes to vectors when this data had already been collected? In 1995, along with a GIS programmer and two other partners, he realized the need for a better way of making maps. This realization led to the creation of Avenza and its main product, MAPublisher. Avenza is now a small but innovative company employing about 10 people. The staff includes an engineer, a web designer/system administrator, a cartographer and a core group of programmers. Avenza is located in Burlington, Ontario, on the outskirts of Toronto.

What is MAPublisher?

MAPublisher is a suite of Plug-Ins and Xtras for Adobe Illustrator and Macromedia FreeHand that bridges Geographic Information System (GIS) technology with high-end graphics software for high resolution printing and electronic publishing technology. Cartographic quality map production is now faster, easier, and better. Avenza understands that GIS graphic tasks are best performed in the right environment such as powerful illustration programs like Macromedia Freehand and Adobe Illustrator. MAPublisher takes you into this environment seamlessly and effortlessly with the right GIS data management tools to facilitate the map production process. Using this fast, intuitive system, your map can transcend the ordinary and become a work of art.

Why Use MAPublisher?
Graphics Functionality Unavailable With Your GIS

MAPublisher gives you the ability to perform GIS tasks in a graphics environment, and allows you to add graphic attributes unavailable with most GIS products on the market. With MAPublisher and Adobe Illustrator or Macromdia FreeHand, you have

* Powerful graphics tools for total control of cartographic visualization.
* Unlimited colour choices including 24 bit colour and the ability to print CMYK four-colour separations.
* The ability to attach text to paths to create natural flowing labels.
* Complete typeface, point size, leading, kerning, tracking and alignment control and the ability to embed text.
* Minimal pre-press and printing problems.
* Automated crop and trim mark creation.
* Trapping for compensation of misregistration.

* The ability to convert custom colours to process colours for printing.

* And all of the other features of your graphics program!

What can I do with MAPublisher?

* Import the most widely used GIS data files (Generate, Shapefile, MID/MIF, DXF, DLG, SDTS).

* Export data Shapefiles, MID/MIF or PDF's.

* Create "Smart" PDF's with queriable databases with pdfPLUS (another Avenza product).

* Import, merge, create and edit any database files.

* View a floating window of map attribute information.

* Assign, edit, analyze and query map attributes.

* Tile map files together in real world coordinates.

* Automate raster image registration of DRG's and other types of georeferenced raster image.

* Automate your legend creation and labeling.

* Change map projections with the fully customizable projection editor (has 119 projections and over 40 ellipsoids).

* Quickly identify geographic locations and display the map scale and anchors in a floating window.

Who Uses MAPublisher?

MAPublisher is used by professionals in a wide variety of fields including geology, engineering, forestry, municipal planning, mining and exploration, graphic design, advertising, real estate, law, defense, newspapers, and television media. Many municipal, provincial, state, federal, and international governments use this product to produce maps and graphics; evidence is provided in talks delivered at this meeting. MAPublisher is being used to teach cartographic concepts at educational institutions around the world. For example, the University of Waterloo uses MAPublisher to teach projections to its students; ITC in the Netherlands uses MAPublisher in combination with ILWIS to teach geomatics concepts from GIS to remote sensing imagery analysis.

CONTACTING AVENZA:

Please visit Avenza's website, <http://www.avenza.com>, for more information about MAPublisher. For examples of MAPublisher maps, check in the Products-Demos section of the web page. If you have any technical or sales questions about MAPublisher, or if you would like to book a training session, you can contact Avenza in a number of ways:

* Sales Department and Order Desk [sales@avenza.com, or tel. (800)884-2555, ex.50]
* General Information [info@avenza.com or tel. (905) 639-3330]
* Technical Support [support@avenza.com or tel. (905) 639 2329]

DesignJet Large Format Printer Trends and Technologies

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HP's Thermal Inkjet Technology (HP TIJ) has been adapted for use in large format printing by the Barcelona Division. TIJ technology has provided high levels of monochrome and color print quality, speed, and reliability at very low cost. TIJ is a relatively new printing technology with lots of life left in it. Performance levels are constantly being increased to meet the emerging needs of technical and graphics printing applications. Users of Geographical Information Systems (GIS) have particularly demanding requirements.

In my talk, I will mention some of the trends shaping GIS, especially the printing part, and how we at HP's Barcelona Division are using those trends to guide us in developing HP TIJ technology. I will highlight the challenges in developing TIJ writing system architectures, talk about future directions, and explain how we collaborate with applications developers such as ESRI and Adobe Systems in our effort to provide more complete solutions.

For information on HP DesignJet products, please consult:

<http://www.hp.com/go/designjet>.

For HP DesignJet post-sales information and other services, please consult:

<http://www.designjet-online.hp.com>.

"Can't See the Geology for the Ground Clutter" — Shortcomings of the Modern Digital Topographic Base

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ABSTRACT

Digital base map data of modern geologic maps must conform to the requirements of the National Spatial Data Infrastructure by containing the following framework data layers: transportation, hypsography (elevation data), hydrography, political units (boundaries), geodetic control, and a cadastral reference system (e.g., PLSS). At the onset of digital mapping a decade or so ago, overall quality of digital base data was quite poor compared to the non-digital, photographic plates previously used in traditional cartographic methods, and it has never adequately improved. These digital geographic base data are currently available from the USGS in four basic formats: DOQs, DEMs, DLGs, and DRGs. DOQs and DEMs are best utilized in conjunction with DLGs or DRGs due to a lack of several types of framework data. Only the DRG contains all necessary framework elements, yet it is not available in high resolution. A case study from a high relief area with a small contour interval clearly illustrates the overall poor quality of this scanned data. All four datasets require extensive modification prior to incorporation into the geologic map. The best solution at present is to generate in-house DRG data by scanning photographic plates at much higher resolution and rubber-sheeting the raster image around the sixteen basic grid control points in Arc/Info.

INTRODUCTION

A geologic map is of little use to anyone if it is not in some manner "grounded" to its appropriate location on the earth by registering it to the topographic base map. At the very least, it must be projected to a known geospatial coordinate system (Universal Transverse Mercator, or UTM, latitude and longitude, etc.), perhaps with an adjacent north arrow, before any scientific editor would consider it acceptable for publication. More importantly, I would argue that the geologic map of the late 1990s should be in compliance with the National Spatial Data Infrastructure (NSDI) and contain essential thematic framework base data on which information (geologic or otherwise) can be accurately assimilated, registered, and integrated. Of the eight themes of geographic data recognized by the Federal Geographic Data Committee (FGDC) as "the **Framework**," the base of any geologic map should contain the following layers: transportation, hypsography (elevation data), hydrography, political units (boundaries), geodetic control, and a cadastral reference system (e.g., PLSS). Digital orthoimagery often provides a dramatic backdrop upon which to display geologic data if the data aren't too "busy." Cadastral land ownership, of all of the framework elements, seems the least important to the geologic mapper. However, in New Mexico, where Indian pueblos and sovereign tribal lands make up almost 20% of the total land area of the fifth largest state of the Union, this is significant geographic data that should be included.

While all of this might seem implicit and rather unnecessary to raise as an issue in a forum of geological mapping professionals, I feel that, to date, this subject matter has not been adequately addressed. In the days of pre-digital cartography, base materials were most often acquired as photographic negative plates from the USGS and then manually manipulated by the cartographer to fit the map as needed. Little thought was given to the types of data presented. The requirement of the base was simply to provide an adequate means of location. With the digital revolution, cartographers quickly began utilizing a wide variety of hardware and software to expedite the map-making process. While in-house map production time was greatly reduced, problems involving file and data sharing grew considerably. Indeed, in response to this, the NSDI was established in 1994 by President Clinton's Executive Order 12906.

At the onset of digital mapping, overall file size was perhaps the most important consideration in practical digital map production. Base data **quality** suffered greatly in an attempt to keep file sizes manageable, when compared to those non-digital base data previously utilized. This was an acceptable trade-off to the overwhelming amount of time and effort saved. Today, with advanced technology and faster computers, base data quality continues to suffer, **unnecessarily**. Base data underpinning geologic maps commonly lack one or more framework elements, are often illegible (either due to poor resolution or from having type or linework set over base information), inaccurate (due to outdated data, a lack of geodetic control, a misregistration of the base data, or some combination thereof), or both. Problems of this nature often result from the inadequate quality of the digital data available. At present, all digital base data require some level of modification to comply with NSDI prior to adding geology. In this paper, I compare and contrast these various digital data and highlight some of their shortcomings.

TYPES OF DIGITAL TOPOGRAPHIC BASE DATA AVAILABLE

Unless geologic cartographers intend to produce their own base data through extensive GPS-surveying and/or manipulating some other remotely sensed data such as airborne radar, they are left with four basic types of digital geographic data currently available from the USGS: digital orthophoto quadrangles (DOQs), digital elevation models (DEMs), digital line graphs (DLGs), or digital raster graphics (DRGs). The USGS National Mapping Division (NMD) defines these datasets as follows:

DOQ – a digital image of an aerial photograph in which displacements caused by the camera angle and the terrain have been removed. They combine the image characteristics of a black and white, color, or color infrared photograph with the geometric qualities of a UTM projection map based on the North American Datum of 1983, and have a 1-meter ground resolution.

DEM – a digital record of terrain elevations for ground positions at regularly spaced intervals primarily derived from published USGS topographic maps.

DLG – these are spatial representations of planimetric information using points, lines, and areas. Currently, the USGS DLG data are distributed as level 3 data (DLG-3), indicating that the data contain a full range of attribute codes, have full topological structuring, and have passed extensive quality-control checks.

DRG – a scanned raster image of a USGS topographic map whose data, inside the map neatline, is georeferenced to the surface of the earth. The raster data have been scanned at either 200 or 250 dots per inch (dpi).

Of these, only the DRG provides the cartographer with all of the framework themes. Yet, given their poor resolution and low quality, cartographers are hesitant to use this product. As stated above, all four types of digital base data must be in some way manipulated and/or combined to generate an accurate, clearly legible, and aesthetically pleasing base upon which to drape a geologic map. Tables I and II summarize the advantages, disadvantages, and necessary modification requirements for each of these datasets.

Very effective base maps can be constructed by combining a DOQ or a DEM with a DLG-3, if any or all of its framework layers are available, but place names and symbology must be added. Combining a DOQ or a DEM with a DRG will also provide effective base coverage if the topographic map data the DRG contains has a suitable contour interval and the data is cleanly sampled. DLG-3s, again, where available, have the advantage of being updated and manipulated because of their vector format, whereas DRGs ultimately only capture the time in which the original paper map was produced. Unfortunately, due to the linear nature of DLG-3s, the data often contain artificial straight line segments and "jaggies," non-smooth, jagged departures from true curves at junctions between straight line segments.

DLG-3 VS. DRG CASE STUDY: PLACITAS, NM 7.5-MINUTE QUADRANGLE

The cartographer, to provide NSDI compliant base data, must rely on either the DLG-3 or the DRG. In areas of complex topography with high relief and a small contour interval, neither digital dataset is adequate. To illustrate this, I present below a case study of a small area of high relief in the Placitas, NM 7.5-minute quadrangle, underlain by a complex Paleozoic and Proterozoic geology.

Methods

Transportation, hypsography, hydrography, and PLSS DLG-3 layers were imported from SDTS into Arc/info format. (Only elevation data is found in the study area depicted below.) In the interest of time, contour labels were left off. Labeling contours with the proper italic font, point size, and appropriate line break distance is a time-consuming task in Arc/Info. The resulting data was exported as a TIFF, imported into Adobe Photoshop, converted to grayscale, and sampled at both low (72 pixels/in, roughly equivalent to dpi) and relatively high (600

Table I. Advantages and Disadvantages of Digital Geographic Base Datasets.

	DOQ	DEM	DLG-3	DRG
Advantages	• Excellent as a shaded background when draped by a DLG-3 or a DRG	• Excellent as a shaded background when draped by a DLG-3 or a DRG	• Vector data allows the user to update map changes	• Inexpensive data (~$1/quad)
	• Transportation, hydrography, landmarks (buildings, etc.) clearly visible	• Hillshading feature gives an appearance of shaded relief	• Points, lines, and areas have attributes	• All types of framework data are present
		• Ability to generate a drainage network		
Disadvantages	• No hypsography, political boundaries, PLSS, typography	• No cultural data, political boundaries, PLSS, typography	• Sparse coverage	• Data quality poor due to low resolution capture (200-250 dpi)
			• Data modification (merging individual layers with their attribute data, assigning plot order, line weights, etc.) time consuming and cumbersome	• Time dependent (static raster data records age of the paper map)
			• Original data quality varies, dependent on digitization quality and quality-control	• Significant cartographic modification necessary (remove colors, hachured areas, areas with screen tints
			• Data contain artificial straight line segments and jaggies	

Table II. Necessary Modifications of Digital Geographic Base Datasets.

DOQ	DEM	DLG-3	DRG
• Spatial Data Transfer Standard (STDS) import	• STDS import	• STDS import	• Run image grid in Arc/Info and remove colors
• Combine quarter quad data and seam together	• Project data (if necessary)	• Merge each data layer with its attribute set	• Generate postscript at appropriate scale and convert to grayscale TIFF
• Add hypsography, political boundaries, PLSS, typography	• Generate hillshade and contours, label contours	• Establish plot order, line weights, etc., label contours	• Remove additional hachured lines, screen tints
	• Generate drainage net (fill sinks, create flow direction and flow accumulation grids, stream order and stream line)	• Convert to grayscale TIFF	
	• Add political boundaries, PLSS, typography	• Add typography	

pixels/in) resolution. Areas of green color on the DRG were rendered white, hachured inundation areas and areas of urban purple and gray screen tints were removed. The image was then converted to both bitmap (1 bit data) and grayscale (16 bit data) and sampled at 72 and 600 pixels/in (Figure 1).

Results

The data depicted in Figure 1 are discouraging. The DLG-3 data at high resolution gives the greatest clarity but the linear nature of the data is often obvious and “unnatural.” The DRG data clearly shows how black pixels representing lines converge, creating an overall blurring effect, as to render the data essentially useless. The low resolution of the initial 250 dpi scan of the paper map is apparent and cannot be fixed, unless done so pixel by pixel in Adobe Photoshop or comparable software.

SO WHAT DO WE DO?

If we are in the business of making geologic maps and are therefore necessarily too busy making geologic maps to have to additionally make the accompanying digital base map, we have three basic options. **(1) Nothing/As Little As Possible**. In this scenario we utilize either the DLG-3 or DRG, perform as little modification as necessary and accept the limits of our data. **(2) Beg.** In this case we implore the National Mapping Division of the USGS to seriously consider the end users, with their modern, powerful, hard drive space-rich computers and re-scan the >55,000 7.5-minute quadrangles of the U.S. at a resolution of at least 600 dpi, a level currently accommodated by most output devices. Why not ask for the data in separates as well? **(3) Fall Back On Memories Of Pre-digital Cartography.** At the New Mexico Bureau of Mines and Mineral Resources, we initially order and purchase photo-

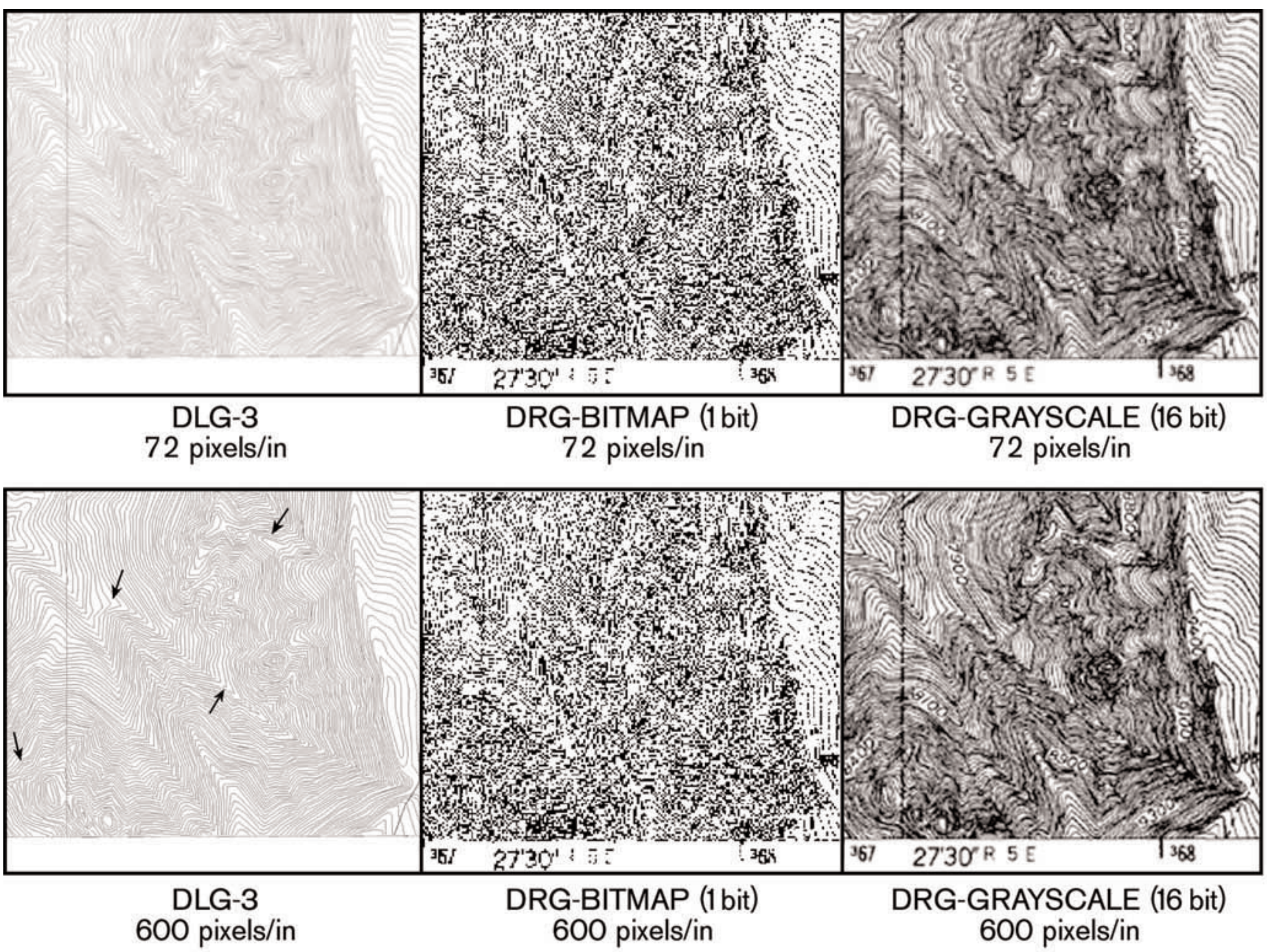

Figure 1. Comparison of DLG-3 base data to DRG base data for a small area of the Placitas, NM 7.5-minute quadrangle depicted at 150% at low and high resolution. Arrows point out several jagged straight line segments common in DLG-3 data.

graphic composite negatives from the USGS-NMD (these are also used to make greenlines). Contract services are obtained to make photographic contact positive prints (we no longer own a Photo Mechanical Transfer camera, having surplused it at the onset of the digital age), and further contracts are made to generate a single 100% TIFF scan of the photographic positive image at the highest resolution possible, as 16 bit data. We are currently able to acquire scans locally at 400 dpi. The scanned raster data is then "rubber-sheeted" about the 16 standard grid control points in Arc/Info to remove distortion, and transported to Adobe Photoshop. The image quality can then be significantly improved by using sharpening filters and adjusting spectrum levels prior to conversion to bitmap. In such a manner we create our own DRG data, at a total cost of $120 for the negative, the film work, and the scan. As seen in Figure 2, the quality of the data is far superior to the USGS 250 dpi DRG data, even at only 400 dpi.

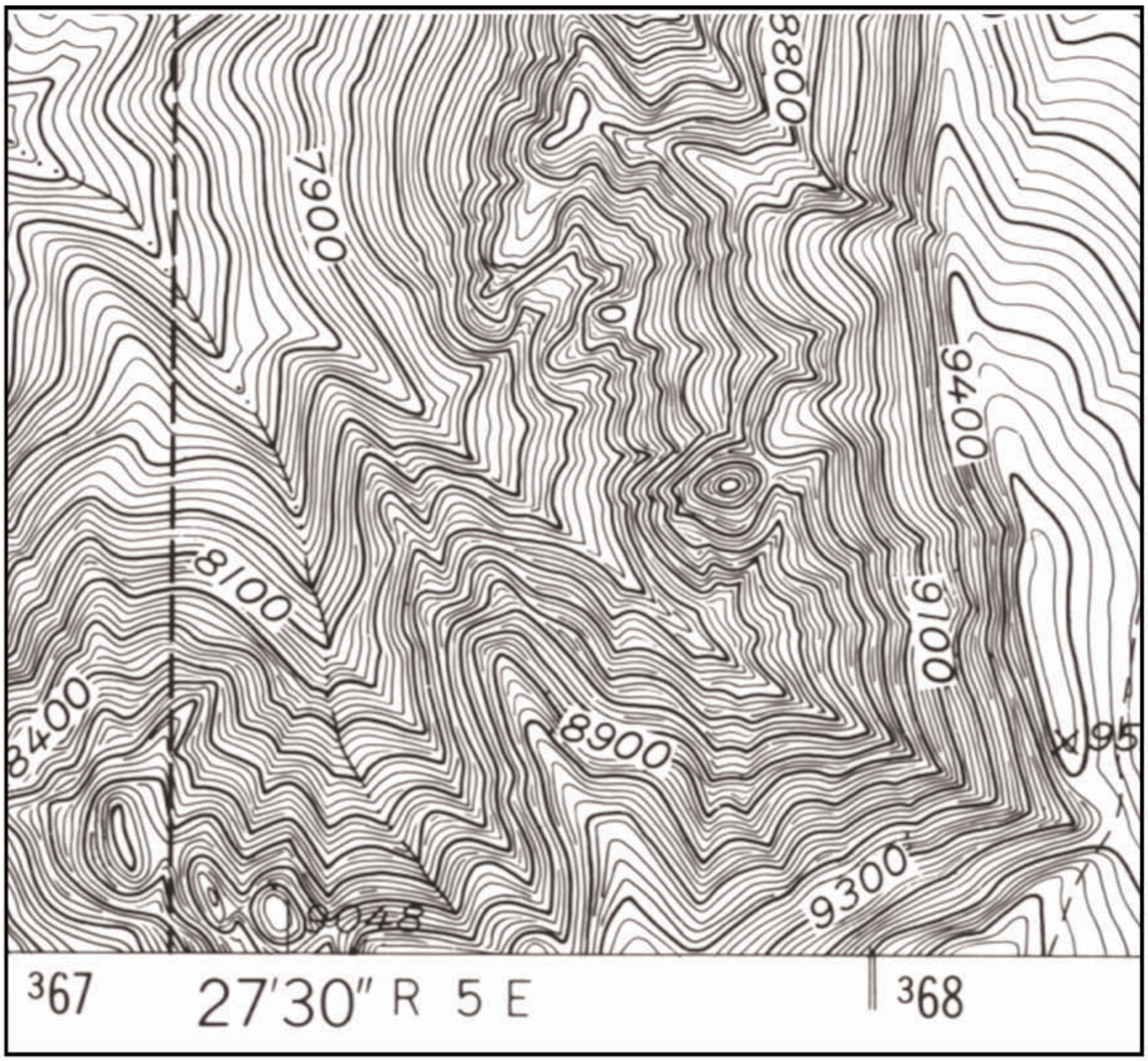

Figure 2. Scanned TIFF image of contact print made from photographic composite negative obtained from USGS-NMD (image at 200% size compared to those of Figure 1). Contact print was scanned at 400 dpi and sampled at 600 pixels per inch.

The Evolution of Topographic Mapping in the U.S. Geological Survey's National Mapping Program

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INTRODUCTION

As the U.S. Geological Survey's (USGS) National Mapping Division (NMD) is challenged to do more with less and at the same time increase its response to customer concerns, the traditional methods of revising the present primary series of topographic maps are no longer feasible. (Primary series maps include 1:20,000-scale quadrangles of Puerto Rico, 1:24,000- or 1:25,000-scale quadrangles of the conterminous United States and Hawaii, and 1:63,360-scale quadrangles of Alaska.) The NMD is responding by continually experimenting and devising new methods by which graphic revision can be accomplished. This proposed approach will provide the means to determine and use the most cost-efficient method(s) for graphic revision. By devising such a revision methodology, that encompasses the concerns expressed in this paper and responding to the needs of our graphic customers, the NMD will become more responsive to the graphic segment of the consumer base and in turn minimize the cost of production.

CHANGES IN THE GRAPHIC REVISION PROGRAM

The USGS National Mapping Program (NMP) has been in existence for over 100 years, and during that time the USGS has established itself as one of the leading civilian mapping agencies in the world. The role of the NMP has been to provide accurate, detailed cartographic and geospatial information for the Nation. This mission has not changed; however, the means of accomplishing that mission and the ways of communicating the resulting information have changed dramatically. During its existence, the USGS has established a consumer base with requirements that greatly exceed the original mandate of supporting just the Federal mapping community. Recent concerns from consumers have heightened our awareness of the effects on mapping that the NMD has had outside the Federal community. They are prompting us to look for a more responsive and inexpensive map maintenance program for our traditional products.

Although the USGS-NMD has historically been known for the large-scale topographic maps produced through its Graphic Revision Program, it has, along with the rest of the mapping industry, made the transition to computer-aided mapping. (Information on NMD's Graphic Revision Program can be found on the Internet at <http://mapping.usgs.gov/mac/isb/pubs/factsheets/fs01698.html>.) During the late 1970's and early 1980's, NMD's Vector Program was created. This program initially focused on the production of digital vector data that used the graphic map as a source. The data collected represented the various feature categories shown on the map. These categories included transportation, hydrography, hypsography, and boundaries, among others. The growth and development of these digital data, defined as digital line graphs (DLG), along with the 1990 Census Program, became the foundation for the geographic information system (GIS) industry and the focus of our future. Our Vector Program contributed significantly to the development of concepts that led to the 1994 signing of Presidential Executive Order (EO) #12906 establishing the National Spatial Data Infrastructure (NSDI) and to the introduction of the framework concept. (Information on NMD's Vector Program is available on the Internet at <http://mapping.usgs.gov/dpi/vector8.html>.) Although this EO was a consolidated effort between multiple Federal agencies, the foundation for it was based on the work previously done by the NMD.

Throughout the evolution of the Vector Program, the graphic customer was viewed as making the digital transition along with the rest of the industry. It was assumed that since graphics were the source for the Vector Program, graphics could easily be derived from this digital product. Digital revision would support the graphic revision requirement since the vectors would reflect change and, in turn, serve as sources for the new graphics. As this concept matured, graphics became more and more dependent upon the existence of digital vectors, to the extent that both the Vector and Graphic Revision Programs were entirely dependent upon the existence and collection of vector information. The NMD still retained an analog graphic process for small-scale and special products, but our primary series became dependent upon the vector source. This dependency has become the underlying focus of many of our present digital production policies and standards. (NMP Geospatial Standards are available on the Internet at <http://mapping.usgs.gov/standards/>.)

In an effort to reduce the expense of both digital and graphic products and to increase their availability, the NMD looked at the product content. In an effort to improve production efficiencies, the NMD reviewed and modified standards for the Vector Program that affected the content of the conventional USGS graphic products. (It should be noted that many content changes also came about because the NMD no longer had the resources to perform field verification.) The public expressed concerns that these vector policies would have negative impacts on the quality and availability of future USGS topographic maps. Many customers have encouraged us to revisit some of these decisions.

Digital production has traditionally been cooperator driven and focused on category-specific collection and revision. This leaves those unrevised or uncollected map categories out-of-date when compared to the newer vector data. This becomes a significant problem when trying to produce a consistent graphic product. The vector-based product generation process uses digital vector data to produce a graphic map. It requires the update of map features to revise the entire quadrangle. Graphic customers have expressed concern that they do not want to be burdened with the additional expense of paying for the production of vectors to produce the graphic product they want. A process that integrates both color separates and existing vector data provides a less expensive revision alternative.

As the GIS industry matures and the State and local governments move their daily activities to GIS-based applications, the NMD is going to be challenged to maintain continuity with regard to the accuracy and content of local GIS holdings. The data sets held and maintained by other agencies in many cases show additional content and are of a newer vintage. To republish a graphic that is out of date compared with local data is embarrassing for the USGS. The Graphic Revision Program needs to maintain consistency with new local data to avoid this problem. This becomes increasingly difficult if policy requires data compatibility between the Vector and Graphic Revision Programs.

The NMD does not have the resources and capacity to meet the demands of the Graphic Revision Program. Therefore, to ensure the production and availability of revised graphic maps, we must use data sources produced by other organizations. A major component of the NSDI is the development and implementation of a national geospatial data framework. As part of the framework concept, NMD will pursue partnerships with other Government agencies and the private sector to use locally produced data that can contribute to its mapping program. We foresee spatial data produced by public and private sector organizations contributing to the revision of our maps. By implementing integration techniques, we can take advantage of these local up-to-date data holdings.

The NMD recognizes the need to find common ground between digital and graphic customers at a minimal expense and without degrading its products. A key approach to this problem is to separate the product dependencies and focus strictly on the customer's needs. This approach prevents the vector cooperator from being burdened by the expense of supporting a graphic product. At the same time, when applied to the Graphic Revision Program, it provides a significant cost savings to the graphic customer. If the Graphic Revision Program is not burdened by the expense to complete vector data to an achievable vector standard, the overall expense to the graphic customer is significantly less.

A goal of the Graphic Revision Program is to produce standard cartographic products regardless of the data sources. The focus needs to be broad enough in scope that it ranges from graphic revision using a full range of digital sources to a reprint process using existing analog techniques. Vectors should be used if readily available but should not be required. If vectors are collected and revised during the graphic process, they should be provided to the Vector Program as transactional updates. If a customer desires both vectors and graphics, the Vector Program can deliver a geographic source for use in an automated generalization process to generate graphics.

The NMD has developed a raster/vector process that will work with existing vector and raster capabilities. This process allows the revision of the graphic map from existing vector or graphic source data. This approach ensures a diverse graphic revision process that uses both analog and digital sources to update products. Figures 1 and 2 illustrate the vector and raster revision processes.

NMD'S CURRENT REVISION PROCESS

The NMD's current method of revising most of its primary series graphic maps is called the raster graphic revision (RGR) process. This method has proven to be the most cost-efficient process for those users who are only interested in acquiring a revised graphic product. The initial prototype project was completed 1.5 years ago. Since the completion of this project, the process has gone through refinements and enhancements and is the method used for most of NMD's in-house graphic revision.

The RGR process was developed to reduce the production costs and the amount of time it takes to revise quadrangle maps, while still meeting customers' needs for a graphic product. This method starts by scanning the map separates at 1,000 dots per inch (dpi) and then making the appropriate additions and deletions to the map detail on the basis of new data sources. For the most part, the sources used are digital orthophoto quadrangles (DOQ). (Information on DOQ's is available on the Internet at <http://nsdi.usgs.gov/products/doq.html>.)

There are two categories of map revision; complete revision and basic revision. In the complete revision process, all features are corrected and updated. Content is validated by field checking against ground truth. Contours are revised. The revised map meets all current NMD standards for feature content and National Map Accuracy Standards for positional accuracy.

In the basic revision process, many features are revised by interpreting image sources, such as digital orthophotos or aerial photographs. The features are not verified through field checking, and contours are generally not revised. The revised map maintains the positional accuracy of the previously published map. Most resources are focused on basic revision because this method is less expensive and more maps can be revised in a given period of time.

As part of the NMD's revision program, a new digital raster graphic (DRG) will be produced for every revised graphic. Recently DRG's, scanned raster images of USGS topographic maps, were completed for all of the USGS primary series maps. (The paper 7.5-minute topographic maps were scanned at 250 dpi.) Since they were produced from the existing paper topographic maps, the DRG's are only as current as the map sources. Now with the raster revision process in place, the NMD can produce a new DRG that reflects the revised graphic. (Information about NMD's DRG's is available on the Internet at <http://mcmcweb.er.usgs.gov/drg/>.)

Although the new DRG's are being produced through a different process, they will adhere to the same standards and specifications that were used during the production of the initial DRG's. Original DRG coverage for the country was produced by scanning the paper topographic map itself. During the raster revision process, each map separate that is scanned and then revised through the raster edit process will be used to produce the DRG. Where we made one scan of the paper map, we will now have a raster scan of each revised color separate. These raster scans will be combined to produce the DRG.

Although this paper describes the transition of NMD's methodology for revising its primary series maps, it should be noted that the NMD does not rely solely on in-house production to accomplish its goals. A significant part of the map production will be accomplished by the private sector through contract work. Within the past year, the NMD has begun contracting some of its revision work. The contractor will steadily increase its share of the revision program over the next few years.

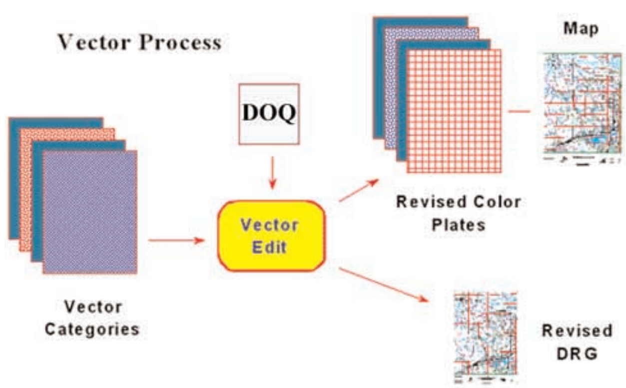

Figure 1. Diagram illustrating graphic map revision through the vector process.

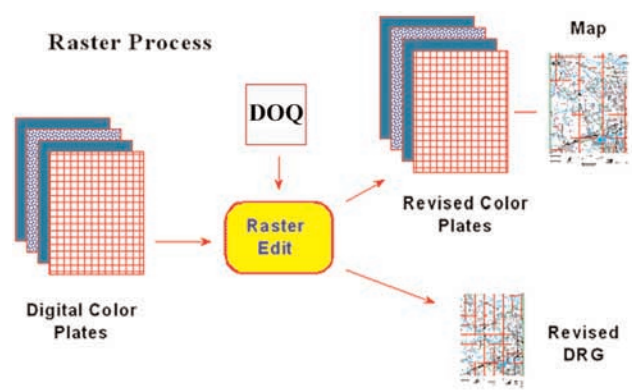

Figure 2. Diagram illustrating graphic map revision through the raster process.

CONCLUSION

As the Nation's need for mapping information continues to grow, the NMD will address this need and be responsive to the map users and their requirements. Its goal is to develop a long-term maintenance strategy that meets the need for revising the primary maps. In addition to providing the user with revised maps more quickly through a more cost-efficient method, the NMD wants to coordinate issues of content, accuracy, and standards with its partners. In NMD, this will be accomplished in great part by building cooperative partnerships with its map users. These partnerships, through shared costs and resources with other organizations, will enable the USGS to meet the increased demand for revised topographic maps of the Nation. With the limited resources and dollars available, we are seeking and encouraging such partnerships to fulfill this need.

The National Geologic Map Database—A Progress Report

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The Geologic Mapping Act of 1992 and its reauthorization in 1997 (PL105-36) requires that a National Geologic Map Database (NGMDB) be designed and built by the U.S. Geological Survey (USGS), with the assistance of the state geological surveys and other entities participating in the National Cooperative Geologic Mapping Program. The Act notes that the NGMDB is intended to serve as a "national archive" of geologic maps, to provide the information needed to address various societal issues. The Act required the NGMDB to also include the following related map themes: geophysics, geochemistry, paleontology, and geochronology. In this progress report, the term "geoscience" is used to refer to these five map themes.

In mid-1995, the general stipulations in the Act were addressed in the proposed design and implementation plan developed within the USGS and the Association of American State Geologists (AASG). This plan was summarized in Soller and Berg (1995). Because many maps are not yet in digital form and because many organizations produce and distribute geologic maps, it was decided to develop the NGMDB in several phases. The first two phases are addressed here. The first and most fundamental phase is a comprehensive, searchable catalog of all geoscience maps in the United States, in either paper or digital format. The users, upon searching the NGMDB catalog and identifying the map(s) they need, are linked to the appropriate organization for further information about how to procure the map. (The organization could be a participating state or federal agency, association, or private company.) The map catalog is presently supported by two databases developed under the NGMDB project: 1) GEOLEX, a searchable geologic names lexicon; and 2) Geologic Mapping in Progress, which provides information on current mapping projects, prior to inclusion of their products in the map catalog. The second phase of the project focuses on public access to digital geoscience maps, and on the development of digital map standards and guidelines needed to improve the utility of those digital maps.

In late 1995, work began on phase one. The formation of several Standards Working Groups in mid-1996 initiated work on phase two. Progress was summarized in Soller and Berg (1997 and 1998). At the Digital Mapping Techniques '98 and '99 workshops, a series of presentations and discussion sessions provided updates on the NGMDB and, specifically, on the activities of the Standards Working Groups. This report summarizes progress since mid-1998. Further and more current information may be found at the NGMDB project-information

Web site, at <http://ncgmp.usgs.gov/ngmdbproject>. The searchable database is available at <http://ngmdb.usgs.gov>.

PHASE ONE

The Map Catalog

The catalog now contains bibliographic information for nearly all formal series USGS maps, USGS maps contained in book publications, and maps from the USGS open-file series. The catalog is estimated to be about 50% complete, and contains georeferenced information for about 90% of all USGS maps (about 18,500 in the catalog) and 6% of state geological survey maps. This represents more than a six-fold increase in information since last year. Through development of a Web-based data-entry form, and reformatting and enhancements to information contained in existing State publications listings, we are working with nine state geological surveys (Illinois, Indiana, Louisiana, Ohio, Oklahoma, Oregon, Vermont, West Virginia, and Wyoming) and one University (Stanford) to bring their map information into the catalog. Entry of state geological survey publications is now a top priority.

Geologic Names Lexicon

In April, 1998, an on-line, geologic-names lexicon, GEOLEX, became available at the NGMDB Web site. This lexicon is under construction, and is estimated to be about 75% complete. At present, GEOLEX contains 90% of the geologic names found in the most recent listing of USGS-approved geologic names; this listing was published in 1996 as USGS Digital Data Series DDS-6, revision 3. Prior to loading into GEOLEX, the information on DDS-6 was consolidated, revised, and error-corrected. Much of the remaining work needed to complete GEOLEX will focus on resolving name conflicts, adding reference summary and other information for each entry, and incorporating geologic names not found on DDS-6 but recorded in the geologic names card catalog at USGS Headquarters. GEOLEX is intended to be the comprehensive, authoritative listing of geologic names approved for usage by the USGS, and is available as a resource for geologic mappers nationwide. Many state geological surveys have been registering new geologic names with the USGS for decades, and are encouraged to continue under GEOLEX, through a Web-based application form.

Geologic Mapping in Progress Database

To provide users with information about current mapping activities at 1:24,000- and 1:100,000-scale (1:63,360- and 1:250,000-scale in Alaska), a Geologic Mapping in Progress Database has been developed. In 1998, its scope and design were proposed to the AASG and a prototype database was built. The database has been expanded to contain information about 1998 mapping activities, and a Web interface to the database has been designed and built. It is available through the NGMDB home page, <http://ngmdb.usgs.gov>.

Related Databases

Work has begun on a National Paleontologic Database and a set of Web pages to permit searches and to provide general-interest information in support of the Database. In the coming year, efforts will be made to provide links from the NGMDB to related databases under construction (for example, for geophysical and geochemical information).

PHASE TWO

Most efforts related to phase two have been directed toward the development of standards and guidelines needed to help National Cooperative Geologic Mapping Program participants more efficiently produce digital geologic maps, and to produce those maps in a more standardized and common format among the various map-producing agencies. Significant progress has been made toward developing some of these standards and guidelines, and increased efforts will be devoted in the coming year toward improving public access to digital maps.

Standards Development

The following summaries concern activities of the AASG/USGS Standards Working Groups formed in mid-1996. General information about the Working Groups, and details of their activities, are available at <http://ncgmp.usgs.gov/ngmdbproject>.

Geologic Map Symbols

A draft standard for geologic map line and point symbology and map patterns and colors, published in a USGS Open-File Report in 1995, was revised by the NGMDB project team and members of the USGS Western Region Publications Group and was circulated for internal review in late 1997. The revised draft is now being prepared as a proposed Federal standard, for consideration by the Federal Geographic Data Committee (FGDC). We anticipate that the draft will be submitted to the FGDC in 1999; informal USGS release of the map symbols and patterns in Postscript format also is anticipated in 1999. To make these symbols more widely available to the GIS community, we have negotiated with Environmental Systems Research Institute, Inc., a cooperative plan to develop an

Arc/Info and ArcView version of the symbols and patterns; for more information, see <http://ncgmp.usgs.gov/ngmdbproject/standards/carto/cartomain.html>.

Digital Mapping

The Data Capture Working Group has coordinated three annual "Digital Mapping Techniques" workshops for state, federal, and Canadian geologists, cartographers, and managers. These meetings have been highly successful, and have resulted in adoption within agencies of new, more efficient techniques for digital map preparation, analysis, and production. The most recent workshop, held in Madison, Wisconsin, and hosted by the

Wisconsin Geological and Natural History Survey, was attended by representatives of 42 state, federal, and Canadian agencies and private companies. The workshop proceedings are published (Soller, 1997, 1998, and this volume) and served on-line (<http://ncgmp.usgs.gov/pubs/of97-269>; <http://pubs.usgs.gov/openfile/of98-487>; and <http://pubs.usgs.gov/openfile/of99-386>). Copies of the Proceedings may be obtained from Soller or Berg.

Map Publication Requirements

Through the USGS Geologic Division Information Council, one of us (Soller) led development of the USGS policy "Publication Requirements for Digital Map Products" (enacted May 24, 1999). A less USGS-specific version of this document has been developed by the Data Information Exchange Working Group and presented for technical review at a special session during the Digital Mapping Techniques '99 workshop (this volume). The revised document (entitled "Proposed Guidelines for Inclusion of Digital Map Products in the National Geologic Map Database") has been submitted to the AASG Digital Geologic Mapping Committee for consideration as a guideline for newly-produced maps available through the NGMDB.

Metadata

The Metadata Working Group developed its final report in 1998. The report provides guidance on the creation and management of well-structured formal metadata for digital maps (see <http:// ncgmp.usgs.gov/ngmdbproject/standards/metadata/metaWG.html>). The report contains links to metadata-creation tools and general discussions of metadata concepts (see, for example, the metadata-creation tools, "Metadata in Plain Language" and other helpful information at <http://geology.usgs.gov/tools/metadata/>.

Geologic Map Data Model

Following numerous presentations, discussions, and progress reports (for example, Raines and others, 1997), in October, 1997, the Working Group posted to the NGMDB project's Web site for public comment a report describing the proposed standard data model. To permit thorough evaluation of the data model, the concepts and specifications described in that report must be translated into software tools that 1) organize and manage the geologic map information in the data-model format, and 2) offer a user-friendly interface for data entry and analysis. The Working Group began building some prototype tools in mid-1997. Through presentations and discussions with potential users, the tools were refined.

The data model and tools were presented for discussion in a special session at the Digital Mapping Techniques '98 workshop in late May, 1998. A number of attendees from the state geological surveys expressed interest in helping to refine the model and develop it into a geoscience-community standard. It was agreed that an extended period of evaluation among the states and USGS would begin as soon as possible.

At a three-day workshop in June, 1998, the first formal review of the data model was conducted. The workshop was attended by 28 members of the USGS, state geological surveys, and the federal and provincial surveys of Canada. An overview of the conceptual model and software tools was followed by a hands-on session and facilitated discussion. The workshop conclusions were to: 1) proceed with development of the data model and software tools; 2) broaden the participation in its further development; 3) begin the extended period of on-site evaluation at state, provincial, and federal surveys; and 4) work toward adoption of the data model as a national standard.

To facilitate the review and discussion of the data model after the June workshop, a Web conference was developed (see <http://geology.usgs.gov/dm/>). Discussion topics include: 1) general conceptual issues related to the data model and geologic mapping; 2) specific problems with the data model; 3) development of standard geologic terms; and 4) software tools. This site, and the NGMDB project's Web site, also offer access to the data model report and software tools.

The workshop's technical review of the data model signaled completion of the Data Model Working Group's task. In late 1998, a mechanism to coordinate the continued development of the data model was proposed to the USGS, AASG, and the Geological Survey of Canada. This mechanism, a Data Model Steering Committee, was accepted in early 1999 and the first meeting was held soon thereafter at the USGS National Center. The Steering Committee is now forming numerous Technical Teams to address discrete tasks deemed necessary to further development and adoption of the data model. These Technical Teams will address issues such as: the inclusion of standard scientific terminology in the model; refinement of the conceptual data model; and development of software tools. Before the Technical Teams begin work, the Steering Committee will contact various users of digital geologic maps and conduct a requirements analysis, to provide information on how they use, or would like to use, digital maps; this information then will help guide the activities of the Technical Teams. Information about the Steering Committee and Technical Teams can be found at <http://geology.usgs.gov/dm/>.

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Proposed Guidelines for Inclusion of Digital Map Products in the National Geologic Map Database

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INTRODUCTION

The enabling legislation for the National Geologic Mapping Act of 1992 includes requirements for development of a National Geologic Map Database (NGMDB), and for standards and guidelines necessary to support its ready access and use by the public. [See the 1992 Act and its 1997 Reauthorization at <http://ncgmp.usgs.gov>]. As detailed elsewhere (for example, in Soller and Berg, this volume), the National Geologic Map Database (NGMDB) is designed as a distributed system developed through consensus among its primary builders, the Association of American State Geologists (AASG) and the U.S. Geological Survey (USGS). It is not intended to be a single entity managed by one group. Because of the rapid evolution of digital mapping and methods for distributing map products, the NGMDB is not a conventional database; primary emphasis has been to develop a searchable catalog of available maps in paper and digital form, at <http://ngmdb.usgs.gov>, and a set of standards and guidelines that are agreeable and beneficial to each agency, described at <http://ncgmp.usgs.gov/ngmdbproject)>.

At some time in the future, the system we are building will lead to a distributed database of digital maps. These maps will be managed by each producing agency and served to the public in a fashion that will enable users to access maps from disparate agencies and use them together, for analysis and display, without the current level of effort required to integrate them. We are now, as a geoscience community, discussing the level of standardization among agencies that is appropriate (and affordable). This paper is intended to contribute to that process.

In August, 1996, technical representatives from the AASG and the USGS met in St. Louis, MO, to identify the standards and guidelines needed to support the NGMDB. As a result, several AASG/USGS Working Groups were formed to conduct the needed work. [Informal minutes of the meeting are available at <http://ncgmp.usgs.gov/ngmdbproject/standards/mtgs/St.Louis>.]

The Data Information Exchange Working Group was charged to develop certain proposed guidelines for producers of digital geologic maps, specifically: "what files and file structure should be "packaged" into a digital geologic map, to promote useability?" In recent years, certainly within the past five, the USGS and state geological surveys have increasingly produced their maps in digital format, and provided them to the public through various mechanisms including traditional over-the-counter sales and the Internet. This Working Group was formed to provide technical advice that could lead to more uniformity to the manner in which geologic map information is provided in these products; not the scientific content, but mostly in the organization and content of the various files that accompany the map. Further information on this Working Group can be found at <http://ncgmp.usgs.gov/ngmdbproject/standards/dataexch/dataexchWG.html>.

This paper is authored by the AASG/USGS Data Information Exchange Working Group, and contains its report. The report is based on earlier (October, 1996) recommendations to USGS participants in the NGMDB and on a new USGS Geologic Division policy ("Publication Requirements for Digital Geologic Map Publication", enacted May, 1999) for which one of us (Soller) was partly responsible while a member of the USGS Geologic Division Information Council. To gather further technical input, the proposed guidelines were presented at the Digital Mapping Techniques '99 meeting, in a special discussion session. The document was well received, and minor changes were suggested. The revised report (contained herein) recently was submitted to the AASG's Digital Geologic Mapping Committee for consideration as a voluntary guideline applicable to all participants in the NGMDB. We emphasize that this is a guidance document, developed collaboratively, and is not meant to proscribe how an agency must release its data. It is intended to provide mapping agencies with information on helpful, typical map data files and documentation that commonly are included in a digital map product made available to the public.

REPORT TO THE AASG DIGITAL GEOLOGIC MAPPING COMMITTEE

Proposed Guidelines for Inclusion of Digital Map Products in the National Geologic Map Database

NOTE - the following DRAFT document concerns a potential cooperative agreement between the AASG and the USGS, in support of requirements of the National Geologic Mapping Act. The Act stipulates the development of various standards, to support the National Geologic Map Database. This document addresses the general format of map products to be made available through the Database. It does not include discussion of a standard data model. It is meant to be an informative guideline, not a requirement, and is intended to provide these agencies and the public with more compatible, better documented, and hence more useable map products. Because digital mapping has evolved rapidly, the specifications in this guideline periodically will be revisited, and may be revised.

Geologic map information supports the needs of a broad range of users. To increase its utility and to promote integration with related data sets produced by other organizations, the information should be readily available, well-documented, and well-structured. The National Geologic Mapping Act of 1992 and 1997 articulates these goals, by stipulating development of various standards and guidelines necessary to promote the more efficient use and sharing of information. The Act calls for these standards to be developed by the AASG and the USGS in support of their cooperatively-built national resource, the National Geologic Map Database (NGMDB). Information is available about the standards now under development, at <http://ncgmp.usgs.gov/ngmdbproject>.

Map users are, increasingly, integrating in a GIS the map products of various geological surveys and other map producers. This integration is made easier where the products are well-documented and share certain common elements (e.g., metadata, browse graphics, readme files). This document addresses only these general elements of a map product, and is intended to promote uniformity among the agencies that collaborate to build the NGMDB. It does not include requirements for a standard geologic map data model, nor does it stipulate scientific content or data interchange format. Those more complex elements of a geologic map and its presentation will require far more discussion among the AASG and USGS.

In the transition from production of maps solely on paper, to production of maps in both digital and paper format, the map's geographic, cartographic,and scientific information has been transformed from a strictly visual medium to one based on electronic files. "Digital" maps now commonly contain the coordinates for various map features, and a database of information about the features, which users may analyze. This document addresses the requirements for preparing a single digital map product for publication, and does not address the integration of data across maps of adjacent areas.

1. CONFORMANCE TO EXISTING REQUIREMENTS — Digital map products (referred to as "products", below) included in the NGMDB will conform to the respective agency's policies and guidelines for approval and publication of products. For example, USGS map products contributed to the NGMDB will conform to Division and Bureau policies, including the requirements of Executive Order 12906, USGS Manual chapter 504.1, and Geologic Division Policy Manual chapter 6.1.3.

2. SCOPE AND RESPONSIBILITIES — These requirements apply to products intended for release to the public in both formal and open-file series. Each agency is responsible for promoting conformance of their products to these guidelines.

3. DATA FORMATS — A specific data format is not required, because of the variety of data systems employed by all cooperators in the NGMDB, and because the NGMDB does not yet provide an online mechanism for users to display and query map data from various agencies. Agencies are, however, urged to provide their map products in one or more commonly-used data formats (for example, Arc/Info export and/or Shape format, AutoCAD format). If the map data are expressed in a non-proprietary format that is not supported by published documentation, the format should be fully and clearly documented in the product.

4. ASSOCIATED FILES — All associated files, tabular and otherwise, containing attribute data should accompany the map data files. Lookup tables and color and line palettes (e.g., Arc/Info symbolsets and shadesets) also should be provided to permit users to display the map data interactively to a monitor.

5. FILE NAMING CONVENTION — For the widest possible usage, file names should conform to the "8.3" convention. This convention requires that file names be limited to 8 characters or less, followed, if needed, by a period and a 3-character extension. An example would be the file name "readme" or "readme.txt". The name and extension should be entirely composed of lower-case (not mixed-case) letters, numerals, underscore, and hyphen. The name should begin with a letter.

6. COORDINATE SYSTEMS — Map data provided in geographic coordinates (latitude and longitude) is most generally useable. The author may choose to provide the map data in geographic coordinates and/or in projected coordinates, in the map projection and ground units typically used for maps of that scale and location (e.g., the UTM projection for 30-minute by 60-minute,1:100,000-scale quadrangle maps, with ground units in meters). To avoid loss of data quality due to resampling during projection, raster thematic (e.g., maps showing spatial variation of a single phenomenon, such as geophysical data) should at least be provided in the original, unprojected form. If the GIS software does not create a file containing essential information about the projection, such a file should be created by the author.

7. BASE MAP — Wherever possible, map products should be georeferenced to a digital base, preferably the one on which the map was compiled. As a service to users, the author may elect to include the base map with the product; this is highly recommended if the base is not published or is not commonly available. If a digital base was used, and if the base was revised to correct for spatial or attribution errors, it should be supplied (in vector or raster format) with the product. Revisions to published base maps should be supported with metadata that describes the data processing. However, not all geologic maps are compiled on a digital base, generally because one is not available. In such cases, it is suggested that a) the base be scanned and georeferenced, b) the geologic map be geoferenced to the base, and c) the base be provided, in vector or raster format, with the product.

8. METADATA — All geologic and base map data should be documented with metadata conforming to the Content Standard for Digital Geospatial Metadata (CSDGM) of the Federal Geographic Data Committee (FGDC). Conformance of the metadata to the structure defined in the CSDGM can be determined using the USGS metadata parser "mp". This parser verifies the specific indented-text format compatible with the Geospatial Data Clearinghouse. This specification should not, however, preclude each agency from exploring other options for managing metadata, including relational databases.

9. README FILE — A brief, overall introduction and guide to the product should be included in a plain-text file named "readme" or "readme.txt". This file should include, but is not limited to, the identity of the product, a brief product description, introductory instructions on how to extract information from the product file(s), a table of contents describing how the product's directories and files are organized, and the location of the detailed metadata.

10. BROWSE GRAPHIC — A low-resolution "browse" graphics file that represents the finished map product should be provided in GIF, JPEG, TIFF, EPS or PDF format. This file is intended to be a relatively simple depiction of the data that enables the user to quickly visualize the map from the author's perspective. Typically, this graphics file is not a fully-detailed depiction of the map data; in such cases the graphic should contain, next to the map image, the following disclaimer: "NOTE: This image is not an authoritative representation of the data."

11. PLOT FILE — The author is encouraged to also include a "plot file" (preferably EPS or PDF), intended to provide the user with the author's full interpretation of the map data. Commonly, these plot files are as detailed as published geologic maps. The decision to include a plot file might be based on the map content and complexity (is the product a complex, multi-purpose geologic map, or simply a derivative map showing areas of greater and lesser geologic hazard?) and the size of the file (will it, with the map product, fit on the intended media?). If a plot file is included, the author should note, in the metadata or readme file, the plotter and the RIP software with which the map has successfully been plotted, and the dimensions of the plot image.

12. PRODUCT FILE — The product should be packaged in one or more files in a universal, cross-platform format. At present, the “tar” and “gzip” formats best fit this description. The decision of whether to use one product file or more should be based on the content and size of the product. Generally, one product file is preferred because product integrity is more easily maintained. However, if the product is relatively large and contains an extensive base map and/or a large plot file, the author may choose to package the plot file or base map in a product file separate from the geologic data. In that case, both product files would contain the readme file. The author should provide in the readme file the information needed to unpack the product file; this may include providing URLs where tar or gzip software may be freely obtained. The product file is intended to provide users with a simple means for copying the product to a local disk, which is especially helpful for products with many data files.

13. SUPPORTING DOCUMENTATION — Potential users of the data may want a brief overview of the product before deciding whether to acquire it. Therefore, authors should provide the following separate files to accompany the single-archive file containing the product (these are duplicates of files contained in the product): the readme file, the browse graphic, and the metadata file in plain-text and, optionally, in HTML format.

Digital Map Production and Publication by Geological Survey Organizations; A Proposal for Authorship and Citation Guidelines

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Geological surveys have begun to produce maps using geographic information systems (GIS) in response to the recent growth in the use of this technology by decision-makers and users in general. In the past, printed reports and maps conveyed geologic information. Now, a survey organization can deliver the same geologic information several ways: as a printed report and map, digital image files, and GIS data files.

Authorship and citation of paper products in literature follow long-standing and well-established conventions, but we have not found any acceptable or established convention for digital publications. This paper reviews several digital products, considers the relationship of authors to their work, and proposes authorship and citation guidelines for these new digital products.

BACKGROUND

Geoscientists are rightly concerned about retaining authorship for map products that they have created. Authors of published maps should expect to see their name on every paper or raster image of a geologic map where they were responsible for the collection of geologic data, synthesis of the data, and "assembly" of the original map. However, authors of these maps should not be liable for errors in a digital reproduction produced by someone else. Vector-data authors should have their name associated with digital files that they create because they share partial responsibility with the original map author for accuracy and error of data in those files. Interestingly, users of the digital files in another GIS or computer application may never look at the original map image (printed or raster) when they query and extract selected point, line or area table data. Clearly, we need a consensus on equitable and clear guidelines for establishing credit and culpability for digital (GIS) data.

The issue is further complicated because the term "digital" map has been applied to a product derived from any of three different procedures. A "digital geologic map" may refer to a simple copy created by scanning an original paper map and producing a raster image. Second, a scanned map image file may be enhanced using computer-graphics software (Adobe, Corel, etc.) to improve colors and linework, to add text, or to alter the explanation (legend). Third, a publication-quality "digital" geologic map may be assembled by capturing the map data in the numerous spatial data (vector) files of a GIS system followed by manipulation of these files to produce a map image. Here, the "intermediate" product (vector files) are also a desired end product.

With each of these three different procedures, there is a correspondingly different level of effort and technical competence required by the creator of the digital product. First, scanning a map and creating a raster image file requires no scientific or technical understanding of the geologic product. Second, enhancing the raster image of the scanned map with computer software and creating a raster image with standardized lines, text and graphic symbols is analogous to scribing and creating peel coats. Again, no scientific knowledge of geology is required to produce the raster map image from an original map, although the replication process requires skilled labor. The result of the first two processes is only an image whether raster or printed.

In the third procedure, GIS conversion requires several steps including invention of a data structure, design and entry of multiple attributes, attention to spatial accuracy, and mathematical conversion of spatial data from one map projection and scale to others. Location error for all points in the GIS files is established by initial georeferencing the scanned map and by computer entry of each point, typically achieved by the digitizer. For GIS conversion of previously published maps, there will always be some horizontal error in the vector data because it becomes separated from its original "married" topographic base. We have found geologic features are most accurately located relative to the original base only. Accurate entry of attribute data into the GIS files requires an interpretation of geologic map data. There are also digital cartographic decisions in the final production of a map image from the GIS (vector) data. The GIS software is used to create tables of alphanumeric spatial data and a final raster map image. Digital conversion of maps into and by a GIS program creates the potential for errors in the GIS table data. These errors in the GIS data files are not obvious by visual examination of the image created from those GIS data files. The errors in the GIS data files are more difficult to expose and repair than errors created through scanning and use of computer graphics software. The result of the third process, (GIS conversion) is an image, raster or printed, and a number of files of alphanumeric GIS data.

Perhaps the relationship of the GIS files to the desired end products obscures authorship issues. Some organizations are interested in creating spatial data files from an existing map and the files are the only end products. Other organizations create GIS files and then use the files to create a final map (raster image and print). If the files are published, both the files and the map are end products; if the files are not published, they are an intermediate product. Furthermore, the GIS files might be compared to the scribed films and stick-up acetates (intermediate products) of the traditional map-making procedure. If the films and acetates could have been "published", who would have been their author? Responsibility for collection of the geologic data, synthesis of the data, creation of spatial data, and assembly of the map should be attributed accurately and consistently for all map products, regardless of the format. This requires clearly stating who is responsible for what.

PROPOSED RESOLUTION

During the search for an established authorship and citation convention and in discussions with the USGS, librarians, and other state geologic surveys, a few ground rules became clear:

1. One who replicates (copies) original work with software and creates only a graphic image does not require the same degree of experience or understanding of geologic science as the original author. Replication contrasts to compilation. Compilation is the creation of a new, modified (from others), different work (map) requiring intellectual effort, experience and understanding of geology. We should maintain this traditional definition and use of "Compilation". There is some confusion created because others have used "Compilation" in new titles or authorship of "digitally converted" older material and may have not made the distinctions here described.

2. The digital files (spatial data) created from any source map are different from the original map material (the image). The author of the digital files could have made errors or omissions. Responsibility and culpability for accuracy of the digital files cannot and should not be assigned solely to the original source author unless the source author created the digital files.

3. Reference to the original geologic map and author should remain intact in any subsequent reworking or adaptation.

4. Realize that every created work has a primary author. Referencing and citing printed material follows an established convention. Referencing and citing digital files and images has no established convention.

SUGGESTED CONVENTIONS

1. If a paper map is produced by a computer-graphics system which does not create digital data capable of being queried or searched, no advancement from the standard way of making maps has been gained and the process is analogous to scribing. Cartographic credit may be given as text printed on the image, but the originator (field geologist, compiler) should retain authorship for the CD-ROM (raster image) and paper print. The term "Digital Geologic Map" should not be used.

2. If the map merely is scanned and an image format or formats made, retain the authorship of the original source on the published electronic media. The title of the work should be "Scanned geologic map of the….", explicitly excluding the word "Digital"; the original mylar or compilation map could be assigned a "Manuscript Map XX" number or, if published, the formal map series number. In the example below, John Doe was the geologist who mapped Walkers quadrangle:

Doe, John, 1997, Scan of the geologic map of the Walkers quadrangle, Virginia: Virginia Division of Mineral Resources Manuscript Map 97-3 (unedited), [CD-ROM; 1997, July 5].

3. When GIS software is used to produce a map image and that image is published (raster or paper), primary authorship remains with the source author (originator). The title of a GIS-created paper map should read "**Digital Geologic Map of**…". Use of the word "digital" in the title clearly indicates GIS data was used and available. Furthermore, a clear distinction should be made between the new GIS-created image and a previously published map. Under the title on the digital map (image), list "**Geology by John Doe**" which gives full credit to the original author for the original work and the map image, printed or raster. Under the author and in smaller font, list something like "**Digital Conversion** (and/or digital editing) **by Jane Smith**" where Jane was the creator of the digital files (GIS files). Because the map is not merely a scan of the original, the relator term "adapted from" is used in the citation:

Doe, J., 1998, Digital geologic map of the Walkers quadrangle, Virginia: Virginia Division of Mineral Resources Digital Publication **DP-5-A** [CD-ROM; 1998, June 21]. Adapted from John Doe, 1997, Scan of the geologic map of the Walkers quadrangle, Virginia: Virginia Division of Mineral Resources Manuscript Map 97-3 (unedited), [CD-ROM; 1997, July 5].

If the map had not previously been open-filed or conventionally printed, the citation (Rader and Gathright are the geologic authors) might simply read:

Rader, E.K., and Gathright, T.M., II, 1998, Digital geologic map of the Front Royal 30 x 60 minute quadrangle, Virginia: Virginia Division of Mineral Resources Map on Demand MOD-12 [1998, September 11].

4. The raster images and paper geologic maps created from GIS spatial data require a different intellectual contribution than that required by computer graphics alone. If the GIS files (tabular data) are published, cite this data separately from the map image by assigning a distinctive title (Digital Publication **DP-5-B**) and appropriate authorship, but link the GIS data to the map image (Digital Publication **DP-5-A**). In addition, relate the GIS data to the source map by using "Adapted from…" in citations. As in the following example, the creator of the vector data is Jane Smith:

Smith, Jane, 1998, Geologic spatial data of the Walkers quadrangle, Virginia: Virginia Division of Mineral Resources Digital Publication **DP-5-B** [CD-ROM; 1998, June 21]. Adapted from John Doe, 1997, Scan of the geologic map of the Walkers quadrangle, Virginia: Virginia Division of Mineral Resources Manuscript Map 97-3.

5. When the original map author is also the creator of the GIS files and the original map has been published, the citation could appear as in #6, below, or as:

Whitlock, W., 1998, Digital geologic map of the Gate City quadrangle, Virginia: Virginia Division of Mineral Resources Digital Publication **DP-10-A** [CD-ROM; 1998, August 10]. Adapted from W. Whitlock, 1997, Geologic map of the Gate City quadrangle, Virginia: Virginia Division of Mineral Resources Open-File Map 97-12.

There would be a companion publication for the GIS vector data, cited as follows:

Whitlock, W., 1998, Geologic spatial data of the Gate City quadrangle, Virginia: Virginia Division of Mineral Resources Digital Publication **DP-10-B** [CD-ROM; 1998, August 10]. Adapted from W. Whitlock, 1997, Geologic map of the Gate City quadrangle, Virginia: Virginia Division of Mineral Resources Open-File Map 97-12.

6. When the mapping geologists compile their own field data on a computer with the GIS software (using the DRG topographic maps for a base), there is no mylar or intermediate product to open-file, unless it is the field notes. Several of our staff in Virginia are currently creating a final map and GIS vector files directly from field data. There could be one or two publications (titles) by the mapping geologist(s):

Berquist, C.R., Jr., 1999, Digital geologic map and geologic spatial data of the Williamsburg 30 X 60-Minute quadrangle, Virginia: Virginia Division of Mineral Resources Digital Publication **DP-25** [CD-ROM; 1999, November 21].

7. Shared authorship and the order of authors would follow normal standards of mutual agreement between those involved with creation of the particular work. This includes consideration of the level of effort of digital compilers and digital editors for authorship of the digital files. Deceased geologic authors will gain a posthumous publication for their geologic map (image) if this convention is adopted.

8. This proposed citation style is somewhat new, and users of map products should be fully informed of this convention for authorship and citation. For example, to insure better understanding, put the following text on the raster (and subsequently printed) map image as well as on the CD-ROM jewel case:

Digital Publication 7 - Appalachia Quadrangle
Digital Publication DP-7-A is the digital map (raster) image. The suggested bibliographic citation for this image of the geologic map or a print of this image is as follows:

Nolde, J. E., Henderson, Jr., and Miller, R. L., 1998, Digital geologic map of the Virginia portion of the Appalachia quadrangle: Virginia Division of Mineral Resources Digital Publication DP-7-A [CD-ROM; 1998, August 26]. Adapted from Nolde, J. E., Henderson, Jr., and Miller, R. L., 1988, Geology of the Virginia portion of the Appalachia and Benham quadrangles: Virginia Division of Mineral Resources Publication 72.

Digital Publication 7B is the digital dataset. Geologic information, concepts, and other products gained from the use of its files should be credited as follows:

Uschner, N. E., Jones, K. B., Sheres, D. E., and Giorgis, S. D., 1998, Geologic spatial data of the Virginia portion of the Appalachia quadrangle: Virginia Division of Mineral Resources Digital Publication DP-7-B [CD-ROM; 1998, August 26]. Adapted from Nolde, J. E., Henderson, Jr., and Miller, R. L., 1988, Geology of the Virginia portion of the Appalachia and Benham quadrangles: Virginia Division of Mineral Resources Publication 72.

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9. Another situation to consider is when a digital map is created from a mylar and this map image has never been published; when the image is printed, it is the first and only paper map available. This paper map can be printed and sold as a map-on-demand (MOD-n). The MOD series should be restricted to products that will never have the associated digital files published. Otherwise, there will be redundancy in the publication (series) nomenclature. For example, the same printed map could have a MOD-x number and a DP-y number (x and y could be different or the same, the result is that there are two series descriptors for the same image). In the example below, the digital files are unavailable (the map could have been produced by graphics-based software). Put the following on the raster map image and consequently the paper map:

The suggested bibliographic citation for this map is as follows:

Rader, E. K and Gathright, T. M., II, 1998, Digital geologic map of the Front Royal 30 x 60 minute quadrangle, Virginia: Virginia Division of Mineral Resources Map On Demand MOD-9 [1998, September 11]. Adapted from Rader, E. K. and Gathright, T. M., II, 1998, Scan of the geologic map of the Front Royal 30 x 60 minute quadrangle, Virginia: Virginia Division of Mineral Resources Open-File Map 98-1 (unedited).

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10. Revisions to publication series such as MODs and DPs are anticipated. When a revision is made to a product, add "revised <date> " to the date in the citation. A second and additional revisions should be added without removing the earlier dates, the same as done for books.

Berquist, C.R., Jr., Uschner, N.E., and Ambroziak, R. A., 2000, Spatial data of the digital geologic map of Virginia: Virginia Division of Mineral Resources Digital Publication **DP-14-B** [CD-ROM; 1999, May 5; *revised 2000, July 5*]. Adapted from Virginia Division of Mineral Resources, 1993, Geologic Map of Virginia: Virginia Division of Mineral Resources, scale 1:500,000.

In summary, these suggestions rely on accepting the notion that a geologic map image is different from GIS spatial data, and that each work may receive a separate title. Relating new and original work by using a phrase "adapted from…" or "modified from…" will help insure complete and accurate citations. Reference to original work may require geological surveys to assign preliminary materials (drafted geology on topographic mylars, manuscript paper maps) to a series such as "Open-File Map" or "Manuscript Map".

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Three online sources of information were also helpful:
<http://www.swem.wm.edu/Gateway/citations.html>
<http://www.uvm.edu/~ncrane/estiles/apa.html>
<http//www.sciam.com/0796issue/0796okerson.html>.

Plain-Language Resources for Metadata Creators and Reviewers

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Mention metadata to people and you'll likely see them cringe. They cringe because metadata lies at the interface between people who create spatial data and the people who would use those data, and it is hard to communicate to a prospective data user all of the wisdom needed to make proper and effective use of the data. Metadata focuses our attention on difficult educational, cultural, and technological issues inexorably linked with the common desire of scientists to see their work valued by other people.

Figure 1 shows how metadata are transferred from data producers to data users. In small, active research groups it is possible to communicate using mostly technical terminology, both because the data producers and data users share a common understanding of the terminology and the circumstances under which the data were produced and because the data users are able to return to the data producers frequently to ask questions. The situation changes drastically when data are made available through the internet to people who are not well known by the data producers. Data users may have different backgrounds and needs, and there are many sources of data available. Consequently data users need metadata that are readily searchable and can be presented in a variety of different formats.

Metadata are readily searchable only if they conform to a standardized structure; they can be presented in a variety of different formats only if they are parseable by computer software. These needs require the metadata to be described using technical terminology that is standardized across many scientific and technical disciplines. But that technical terminology is often unfamiliar to specialists in any one discipline. Hence metadata are not only hard for producers to write, they are also hard for reviewers and end-users to read. Plain-language approaches provide solutions directed at easing specific troubles encountered in writing and reading metadata.

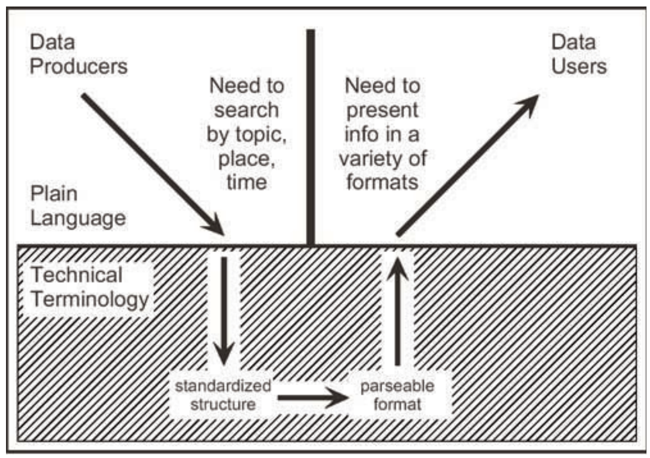

Figure 1. Diagram depicting the flow of metadata from data producers to data users. This information transfer cannot occur using plain language alone because unstructured information cannot be reliably indexed by topic, place, time, and other characteristics, nor can it be reliably reexpressed in a variety of formats suiting the needs of diverse users. Consequently the metadata must be expressed using some technical terminology in a standardized structure and parseable format; these allow computer software to index it appropriately and reexpress the metadata in plain language as well as technical terminology.

PLAIN-LANGUAGE APPROACHES TO CREATING, REVIEWING, AND READING METADATA

1. Understanding Metadata and Learning How to Write it

Metadata in Plain Language: A guide for metadata creators and reviewers:

<http://geology.usgs.gov/tools/metadata/tools/doc/ctc/>

The goals of these pages are to put the metadata standard's many elements into perspective and to show how to create a metadata record using a heuristic procedure. They present the FGDC metadata standard as a series of plain-language questions; for each question they show which elements of the metadata standard should hold the answers, and how to express the answers correctly.

2. Expressing Metadata as Answers to Standard Questions

The USGS metadata parser mp reads, checks, and re-expresses metadata:

<http://geology.usgs.gov/tools/metadata/tools/doc/mp.html>

MP checks the structure of metadata against the FGDC standard, indicating where and how the metadata record doesn't conform. MP then re-expresses the metadata in a variety of formats that are likely to be useful in different ways. MP can create SGML, XML, parseable text (its input formats), as well as HTML and DIF, a form used by the NASA Global Change Master Directory. Of particular interest is the new FAQ-style HTML, which presents the metadata as answers to the same plain-language questions given in Metadata in Plain Language. The abbreviation FAQ as commonly found on the internet refers to frequently-asked questions; since metadata are produced before a data set is used extensively by the public, FAQ here refers to frequently-anticipated questions. This form is likely to be more readable by people who are unfamiliar with the FGDC standard.

How to generate FAQ-style HTML using mp:

The simplest method is to invoke mp with the `-f` option:

```
mp info.met -f info.html
```

This will place into the file `info.html` the FAQ-style HTML output.

An alternative method is to specify the form of the file name in a config file. Under `output:html` the name of the FAQ-style HTML output is specified using the element faq as follows:

```
output:
  html:
    file: %s.html
    faq: %s.faq.html
```

Here the `file` element contains a *template* showing how mp should compose the name of the outline-style HTML file; in the template, the string `%s` is replaced with the name of the input file (with its extension removed). Likewise, the `faq` element contains a template showing how mp should compose the name of the FAQ-style HTML file.

Note that the Clearinghouse server software currently in use (May-1999) assumes that if the SGML metadata document selected is info.sgml (for example) then the HTML document to be returned to the user is info.html. That strategy will normally return the outline form of HTML to the user. If you wish to return the FAQ-style HTML first, then you should change the values shown above like this:

```
output:
  html:
    file: %s.out.html
    faq: %s.html
```

Using these config file elements, the FAQ-style output will be the one returned by the server through a Z39.50 PRESENT request.

NOTE: mp now provides in its HTML output a link to each of the other output formats that you requested when running mp. These links are relative to the current directory by default, and will work correctly when someone retrieves a metadata record directly through a web server. However, HTML metadata records retrieved through the Clearinghouse gateway interface come tagged with the URL of the gateway, consequently these links will not work by default with HTML records found through the gateway interface. To make these links work without regard to the retrieval method, place a BASE tag into the HEAD element of the output HTML code. As you might guess, mp can do this for you, but it needs to know the URL where your metadata will be available as web pages. It gets this information from a config file entry as follows:

```
output:
  html:
    base: URL
```

So if your web site has a URL like

<http://www.our-data.org/metadata/>

that will contain your metadata records, put this into your config file:

```
output:
  html:
    base: http://www.our-data.org/
          metadata/
```

Obviously you have to use the -c config_file command line option for mp, substituting for config_file the name of the actual config file you'll be using.

How mp writes FGDC metadata elements in plain language:

`<http://geology.usgs.gov/tools/metadata/tools/doc/plain.faq.html>`

This is a specially constructed record showing how mp composes plain-language output from FGDC elements. Generated entirely by mp, it shows where the elements of the metadata standard appear in the output as answers to questions. This file should not be regarded as authoritative, since there are many choices that must be made when creating metadata, however it may help people to understand how mp composes answers to the plain-language questions using the standard FGDC elements.

3. Examples Showing Plain-Language and Technical Terminology

Geology of the onshore part of San Mateo County, California: A digital database

Questions & Answers (FAQ-style HTML)
`<http://geo-nsdi.er.usgs.gov/metadata/ofr98137.faq.html>`

Outline (original-recipe HTML)
`<http://geo-nsdi.er.usgs.gov/metadata/ofr98137.html>`

Parseable text (not HTML)
`<http://geo-nsdi.er.usgs.gov/metadata/ofr98137.met>`

Additional examples can be found on the U.S. Geological Survey Geoscience Data node of the National Geospatial Data Clearinghouse, at `<http://geo-nsdi.er.usgs.gov/>`.

ArcInfo 8: New GIS Technology from ESRI

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ArcInfo Version 8 contains the same core applications as Version 7.x. These applications—ARC, ARCPLOT, and ARCEDIT— have been enhanced and updated. This ensures binary compatibility with any application developed using Version 7.x. Three new applications, Arc Toolbox, Arc Catalog, and Arc Map, provide easy-to-use, Windows-style user interfaces that make working with ArcInfo easier than ever before. The new component object data model introduced in Version 8 goes beyond traditional point, line, and polygon features and allows modeling of objects, such as power poles and electrical switches, in a more realistic way. These new applications are highly customizable.

Information about the Environmental Systems Research Institute, Inc. (ESRI) and its products, including ArcInfo and ArcView, can be found at <http://www.esri.com>. A short summary of new functionality in ArcInfo Version 8, as published in ArcUser magazine, is available at <http://www.esri.com/news/arcuser/0499/ai8b.html>. For information on application of ESRI products in the earth sciences (e.g., collaboration with USGS on development of symbolsets and patternsets for geologic features) or to offer suggestions or discussion, please contact me.

Extracting the Information from 3D Geologic Models — Maps and Other Useful Outputs

By Skip Pack

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As commercial companies such as Dynamic Graphics, Inc. (developer of the 3D geologic sturcture and property-modeling system, EarthVision™), universities, the various geological surveys, and other research organizations have extended traditional mapping techniques toward creation of true 3D geologic structure and property models, access to the information in those models for external uses has not been as good as it ultimately needs to be. One of the primary benefits of a 3D geologic structure modeling system is the enforced consistency of the component zones, fault blocks, and surfaces that comprise the model. Such a model is easily viewed on a computer, picked apart, sliced, rotated and so on . . ., but creating maps, sections, and other electronic outputs from such a model is very important if that model is to be more than a nice curiosity to anyone other than those who can view it on a computer. In this talk, I will review the process of creating such maps, sections and outputs, and discuss why such maps represent an improvement over maps developed independent of an underlying model.

For further discussion on 3D models and their relationship to mapping outputs, please refer to <http://www.dgi.com> and/or contact Skip Pack (email: skip@dgi.com).

Ground Water Atlas of the United States

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The Ground Water Atlas of the United States presents a comprehensive summary of the Nation's ground-water resources, and is a basic reference for the location, geography, geology, and hydrologic characteristics of the major aquifers in the Nation. The information was collected by the U.S. Geological Survey (USGS) and other agencies during the course of many years of study. Results of the U.S. Geological Survey's Regional Aquifer-System Analysis Program, a systematic study of the Nation's major aquifers, were used as a major, but not exclusive, source of information for compilation of the Atlas. The Atlas includes 14 chapters, 13 of which are published separately, representing regional areas that collectively cover the 50 States and Puerto Rico. These chapters are published in the Hydrologic Atlas series with numbers ranging from HA-730B through HA-730N. The remaining chapter, Chapter A, serves as an introduction and national summary. Chapters will also be collated into a single bound volume (figure 1).

ATLAS ORGANIZATION

The Ground Water Atlas of the United States is divided into 14 chapters. Chapter A presents introductory material and nationwide summaries; chapters B through M describe all principal aquifers in a multistate segment of the conterminous United States; and chapter N describes all principal aquifers in Alaska, Hawaii, and Puerto Rico.

	Chapter content	Hydrologic Atlas Chapter
–	Introductory material and nationwide summaries	730-A
1	California, Nevada	730-B
2	Arizona, Colorado, New Mexico, Utah	730-C
3	Kansas, Missouri, Nebraska	730-D
4	Oklahoma, Texas	730-E
5	Arkasas, Louisiana, Mississippi	730-F
6	Alabama, Florida, Georgia, South Carolina	730-G
7	Idaho, Oregon, Washington	730-H
8	Montana, North Dakota, South Dakota, Wyoming	730-I
9	Iowa, Michigan, Minnesota, Wisconsin	730-J
10	Illinois, Indiana, Kentucky, Ohio, Tennessee	730-K
11	Delaware, Maryland, New Jersey, North Carolina Pennsylvania, Virginia, West Virginia	730-L
12	Connecticut, Maine, Massachusetts, New Hampshire New York, Rhode Island, Vermont	730-M
13	Alaska, Hawaii, Puerto Rico	730-N

Figure 1. Organization of the Ground Water Atlas of the United States.

The main objective of the Ground Water Atlas was to produce an attractive and easy to follow product with text, charts, photos, cross sections and diagrams which explain technical terms in simple language. It attempts to clearly illustrate the principles that govern the movement and occurrence of ground water in different geologic and topographic settings. To accomplish this task, hydrologists from the Water Resource Division of the USGS were assigned to each of the 14 chapters based on their knowledge of the ground water in the area. The authors compiled from previously published reports. Graphics and maps from a variety of sources were used or modified and original graphics were added where needed. Graphics and text were forwarded to a USGS office, the Cartography and Publishing Program (CAPP) in Madison, Wisconsin, for publication production.

The coordination of design for the atlas series was an enormous task, selecting colors, patterns and cartographic symbolization for each aquifer and insuring that those design decisions made in the early chapters could be applied to all 14 chapters. In its history, production methods for the Ground Water Atlas have changed from exclusively traditional to exclusively digital cartographic methods. A publication requirement was to make all chapters appear like a single product regardless of the production methods used. The first two chapters, 730-G and 730-J, were done using traditional cartographic methods, needing scribe coats, peel coats, type flaps and many hours of darkroom work to produce. The following two chapters, 730-H and 730-C, had incorporated digital elements in their production. Basemap line work was created in Arc/Info using USGS DLGs imported into Adobe Illustrator on the Macintosh platform for annotation. Other simple graphics were completed in Illustrator as well and imaged to a page-size image setter. With the addition of a large size film plotter in 1993, the next chapter, 730-K, and all subsequent chapters have been produced digitally. Arc/Info was used for all base and aquifer outcrop data, Adobe Illustrator for figure production, Adobe Photoshop for photo manipulation, and Adobe PageMaker for text, layout and creating separates. Producing these chapters digitally has saved time in production, eliminated almost all darkroom work and cut the time spent making corrections by 80 percent.

As of mid 1999, 12 of the 13 regional chapters have been published and are available. Chapter 730-N is expected to be published late in 1999 (figure 2). The bound hard cover volume of all 14 chapters is also expected to be released in fiscal year 2000. Several chapters are available at the following web site: <http://wwwcapp.er.usgs.gov/publicdocs/gwa/index.html>. This web site, which is currently under construction, will contain all 14 chapters when completed. Chapters produced using traditional cartographic methods will be available for viewing as JPEGs and downloadable in TIFF file format. Chapters produced using digital cartographic methods will be viewable as GIF files and downloadable as compressed EPS files.

As a result of the Ground Water Atlas activities, a national map, the "Principal Aquifers of the United States", and an associated data set have been published and are available as part of the "National Atlas of United States ™". The data and map describe the distribution of principal aquifers across the country with each aquifer being classified as one of six geologic material types. The data and printed map are available from the "National Atlas of United States" web site at: <http://www-atlas.usgs.gov/atlasmap.html>. The aquifer data is downloadable in several formats including SDTS, shape files or ARC export file format. Links to the aquifer data and metadata can be found from either the Ground Water Atlas or National Atlas of the US web sites.

Availability of the Ground Water Atlas of the United States

Hydrologic Atlas chapter	Publication status, May, 1998
HA 730-B	published 1995
HA-730-C	published 1995
HA-730-D	published 1997
HA-730-E	published 1996
HA-730--F	published 1998
HA-730-G	published 1990
HA-730-H	published 1994
HA-730-I	published 1996
HA-730-J	published 1992
HA-730-K	published 1995
HA-730-L	published 1997
HA-730-M	published 1995
HA-730-N	published 1999

Figure 2. Status of Ground Water Atlas chapter publication.

Acquisition of Geologic Quadrangle Data from a Digital Index Map—A New ArcView Application to Geologic Data Query

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INTRODUCTION

The Kentucky Geological Survey (KGS) is currently in the process of converting a statewide set of geologic quadrangle (GQ) maps to digital format (Anderson, 1998). Since geologic maps are usually highly detailed and complicated, the KGS devised a standardized procedure for GQ data capture and attribution, in which data for a particular quadrangle are segregated into multiple Arc/Info data layers based on the nature of the geologic data (Anderson and others, this volume). For each GQ, lithologic formations, structure contours, mineral resources, faults, coal resources, fossils, drill holes, and igneous dikes are captured and attributed as separate coverages or data layers. Each data layer may consist of one or more feature data types (e.g., polygon, arc, or point). These coverages are stored under an Arc/Info workspace named after the quadrangle. There are 707 geologic quadrangle maps that cover Kentucky. Eventually, the KGS digital GQ database will contain 707 Arc/Info workspaces and several thousand Arc/Info coverages. Therefore, populating data from this spatial database for map manipulation is an important issue. So that users of the digital GQ database will not have to browse through the database to find particular coverages, and then load them one by one, we introduce a new ArcView application, called GQ Data Query, that acquires spatial geologic data from a spatial database through an interactive index map.

ALGORITHM OF GQ DATA QUERY

GQ Data Query can significantly automate access to, and display of, digital GQ data. It allows a user to load geologic data for any quadrangle by selecting that quadrangle in a digital index map. The algorithm of GQ Data Query is analogous to acquiring a paper GQ map from an organized map storage. The algorithm can be illustrated as the following basic steps: (1) locate a quadrangle by selecting the polygon that represents the quadrangle on the index map, (2) retrieve the quadrangle name by accessing the attribute table of the index coverage, (3) identify the data source where the Arc/Info workspace for the selected quadrangle is located, (4) identify all existing Arc/Info coverages under the workspace, and (5) extract and display all the Arc/Info coverages under the workspace (Fig. 1).

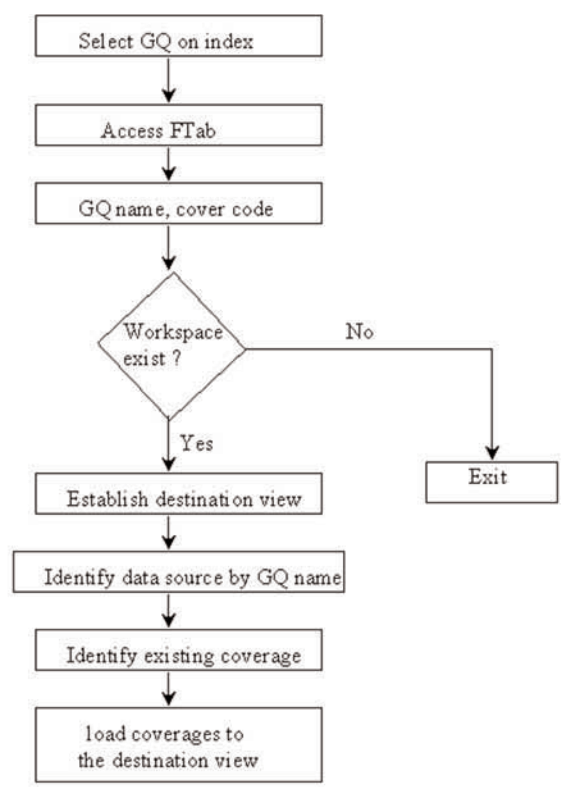

Figure 1. Algorithm and implementation of GQ Data Query.

Developed through the Avenue scripting language, GQ Data Query consists of the following major components: a 7.5-minute index map coverage, an external database file that stores the metadata for all individual quadrangles, and a set of Avenue scripts. The Avenue scripts are customized to associate with a button and the Load Data menu under View in the standard ArcView 3.1 interface, so that a user will be able to load all geologic data pertinent to a selected quadrangle by either pushing the button or selecting the menu. The database file is used to link the polygon attribute file of the index polygon coverage to form a virtual table, which then serves as a linkage between the index coverage and the actual GQ data. A user can also obtain metadata for any particular quadrangle through the virtual table, such as quadrangle name and number, latitude and longitude, publication date, and author name. If the index map is overlaid with other coverages such as county boundaries and road networks, a user will be able to identify the spatial relationship between a quadrangle, road network or county area.

EXAMPLE

Figures 2 and 3 illustrate a typical working session of GQ Data Query. When the ArcView project is opened, a 7.5-minute index map is displayed. On the index map, some quadrangles are highlighted initially to indicate that digital geologic data for these quadrangles are currently available (Fig. 2, top). The desired quadrangle can be selected either through query by using the Query Builder (by name or map number) or through mouse click after zooming in (Fig. 2, bottom). After a quadrangle is selected on the index map, the geologic data can be loaded simply by pushing the Load GQ Data button or selecting Load Data menu (Fig. 3, top). If users want to extract data for multiple quadrangles, they will be given an option to populate data on an existing view if quadrangles are adjacent to each other (Fig. 3, bottom) or create a new view.

REFERENCE

Anderson, W.H. 1998, History of geologic mapping at the Kentucky Geological Survey, in Soller, D.R., ed., Digital Mapping Techniques '98-Workshop Proceedings: U.S. Geological Survey Open-file Report 98-487, p. 9-12, <http://pubs.usgs.gov/openfile/of98-487/anderson.html>.

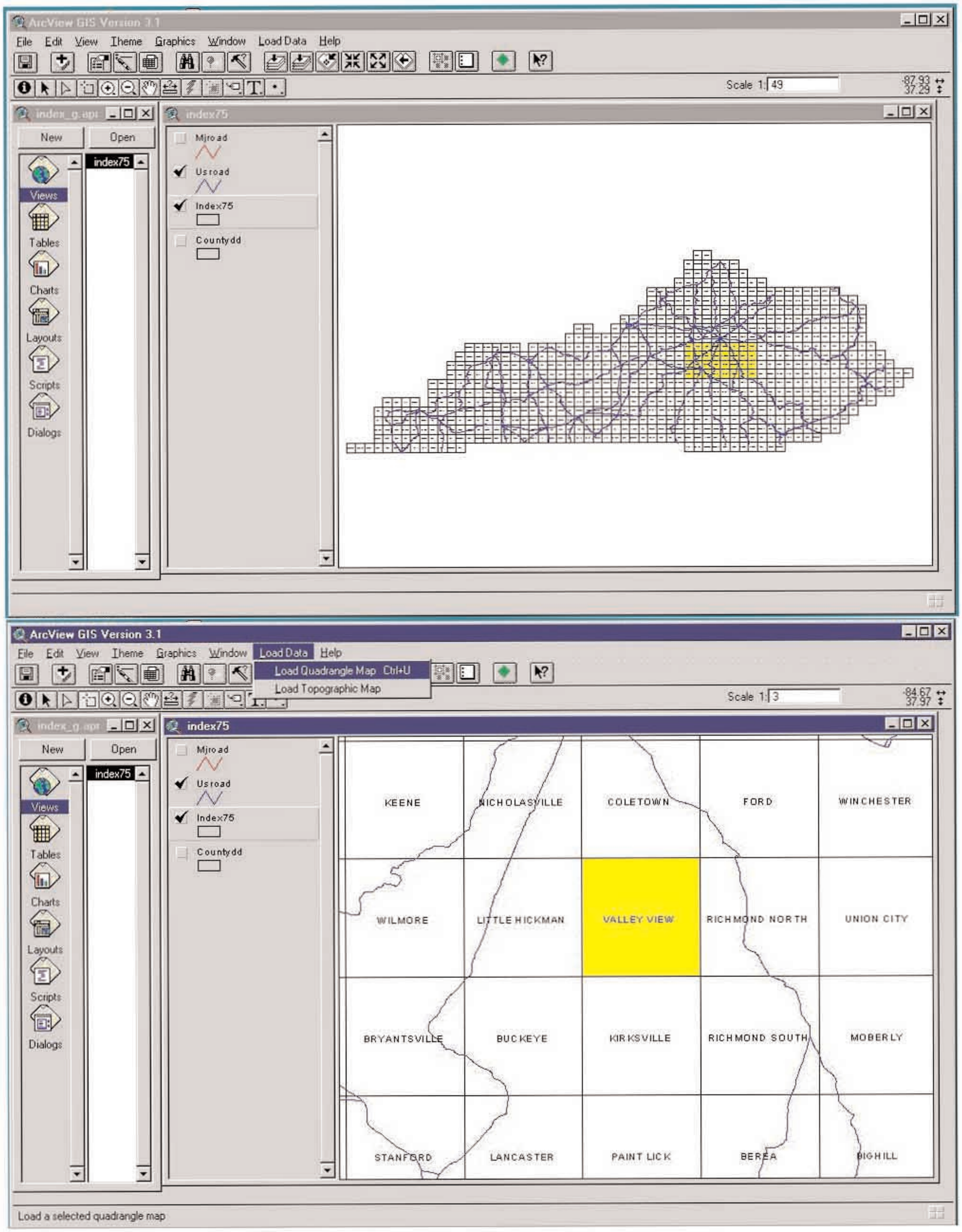

Figure 2. A typical working session of GQ Data Query: (top) an interactive index map as a graphic interface of ArcView GIS; (bottom) select a quadrangle on the index view.

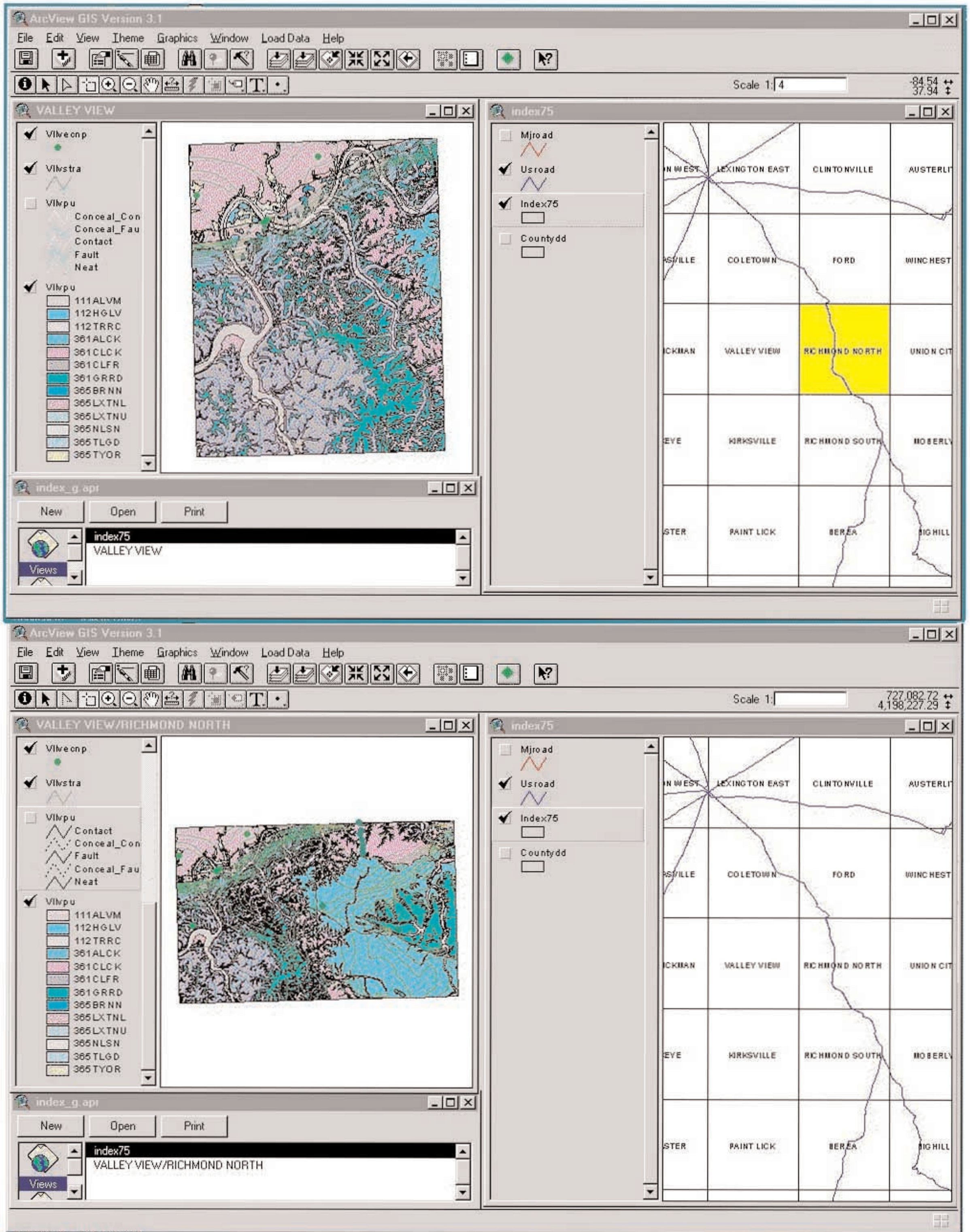

Figure 3. A typical working session of GQ Data Query (continued): (top) loading a geologic quadrangle; (bottom) loading two adjacent quadrangles.

Progress Toward Development of a Standard Geologic Map Data Model

By the Geologic Map Data Model Steering Committee

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In August 1996, representatives of the Association of American State Geologists (AASG), the Geological Survey of Canada (GSC), and the U.S. Geological Survey (USGS) met in St. Louis, MO, to discuss the development of various standards and guidelines for geologic maps contributed to the National Geologic Map Database (NGMDB). As a result, working groups were formed to address geologic map symbology, data capture, metadata, map publication, and a conceptual data model (see <http://ncgmp.usgs.gov/ngmdbproject/>). The Data Model Working Group began its work shortly thereafter and, through numerous public presentations, discussions, and progress reports (for example, Raines and others, 1997; Soller and others, 1998), in October 1997, the Working Group posted to the NGMDB project's Web site for public comment a report describing the proposed standard data model. The initial public version was superceded by a more mature one in May 1998 (version 4.2, Johnson and others, 1998a). A technical review of model version 4.2 was conducted at a 3-day workshop in June 1998. Minor revisions subsequently were made, and the most current version, 4.3 (Johnson and others, 1998b), was released.

At the Digital Mapping Techniques '98 workshop, the data model was discussed extensively, and various agencies expressed interest both in furthering its conceptual development and in testing its implementation with their geologic maps. We are pleased to note that many of the papers given at this meeting (DMT'99) provide evidence of this committment, and of their interest in continuing the effort to develop a standard data model for the geoscience community.

With technical review and release of version 4.3, the Data Model Working Group had completed its task. The agencies involved in this effort then devised a mechanism to promote further development of the conceptual model and the various implementations that would be required among the participating agencies. This mechanism, the Data Model Steering Committee, provides overall guidance, coordination, publicity, and communication for the development of a digital geologic map data model to support, at a minimum, the needs of the United States and Canadian geoscience community. In early 1999, the first meeting was held, and a charter was written (see <http://geology.usgs.gov/dm/steering/charter.html>). The second meeting was held at the DMT'99 workshop, and included the development of plans for various technical teams to conduct specific tasks. These teams will address:

- Requirements Analysis (to refine our understanding of the data analysis requirements of various users);
- Data Model Design (to continue refining the conceptual model based on the Requirements Analysis, delibera-

tions of the other technical teams, and user comments);

- Scientific Language Technical Team (to develop standard terminologies for the various elements that comprise geologic maps, e.g., rock classification);

- Software Tool Development (to design tools that meet user needs as specified in the Requirements Analysis);

- Data Interchange (to develop translators among various implementations of the conceptual model);

- Documentation (to improve public understanding of data model design and software tools).

Information concerning the Steering Committee and the technical teams are posted to the data model Web conference site, <http://geology.usgs.gov/dm/>. Interested persons are invited to register at the site and contribute to the data model's continued evolution.

REFERENCES

Johnson, B.R., Brodaric, Boyan, and Raines, G.L., 1998a, Digital Geologic Maps Data Model, v. 4.2: AASG/USGS Data Model Working Group Report, <http://geology.usgs.gov/dm/>.

Johnson, B.R., Brodaric, B., Raines, G.L., Hastings, J., and Wahl, R., 1998b, Digital Geologic Map Data Model v. 4.3: AASG/USGS Data Model Working Group Report, <http://geology.usgs.gov/dm/>.

Raines, G.L., Brodaric, Boyan, and Johnson, B.R., 1997, Progress report—Digital geologic map data model, in David R. Soller, ed., 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, p. 43-46, <http://ncgmp.usgs.gov/pubs/of97-269/raines.html>.

Soller, D.R., Brodaric, Boyan, Hastings, Jordan, Johnson, B.R., Raines, G.L., and Wahl, R.R., 1998, Progress Toward Development of a Standard Geologic Map Data Model, in David R. Soller, ed., Digital Mapping Techniques '98 — Workshop Proceedings: U.S. Geological Survey Open-File Report 98-487, p. 47-48, <http://pubs.usgs.gov/openfile/of98-487/soller3.html>.

Geologic Concept Modeling, with Examples for Lithology and Some Other Basic Geoscience Features

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ABSTRACT

Digital geologic maps are a cornerstone of next generation geologic information systems that will archive, query, retrieve, and display geologic information tailored to specific requirements. These systems will probably include a knowledge base component to support applications that check the consistency of existing 'knowledge' with new interpretations and data. In order to maximize the utility of such a system, a standard conceptual data model must be developed. The purpose of a conceptual model is to provide a consistent framework for developing logical and physical models specific to particular software/hardware systems. It is difficult or impossible to transfer data between information systems implemented using inconsistent underlying concepts. Many subsets of earth science overlap with other disciplines, and development of conceptual models in these domains can take advantage of similar efforts in other fields. Two domains of discourse that are particular to earth science are 1) the description and classification of rocks (lithology), and 2) the description of spatial relationships necessary to deduce the relative ages of rock units and structures (map-scale relationships). A conceptual model of these domains describes the component parts, and the relationships between the parts.

Rock hand samples are small relative to our bodies (1-20 cm), and contain a very large number of constituent parts (grains). These parts can be classified into different types characterized by their size, composition, and shape. Hand-sample lithology is described in terms of a set of constituent parts defined by generalized characteristics, and the typical relationships between the types of constituents. A complete lithology description defines the set of constituent part types, the fraction of each type in the whole (modal petrography), and the typical relationships between grains of each type. The set of constituent types may be defined based on one or more criteria involving size, shape and composition. The composition of a constituent type may be a single mineral or another lithologic entity (e.g. clasts in conglomerate, leucosome in migmatite). Description of the relationships between grains includes information about the texture and fabric of the aggregate. Common lithologic terms may specify characteristics of only one aspect of the aggregate: e.g. grain size (sandstone), grain shape (breccia), fabric (schist), or grain composition (hornblendite).

On a 'map scale' (1-100 km), geologic objects are large compared to our bodies, and are internally variable. Earth features at map-scale are described in terms of a set of rock bodies defined by generalized characteristics, and the surfaces that bound the rock bodies. A set of necessary and sufficient conditions is required to define the identity of each rock body. Each rock body is bounded by a set of intersecting surfaces that define a volume at a particular geographic location. In many cases, one of the bounding surfaces is the Earth's surface. The other bounding surfaces are referred to as geologic surfaces. These may be depositional, intrusive, gradational, faulted, or polygenetic. Geologic surfaces are typically directed. A depositional or intrusive contact is directional if rock on one side is known to be older than rock on the other side. A fault is directed if the orientation of the slip vector is known. A gradational contact can have a sense defined by the gradient of some physical property. Polygenetic contacts may not have an inherent directionality, or they may have one or more directions inherited from stages of their genesis. Geologic surfaces commonly have properties, for example boundary layer thickness, rock types unique to the boundary (fault rocks, soil profile, basal conglomerate...), and small-scale geometry of the surface (rough, smooth, interleaved, etc.).

INTRODUCTION

Geologic data are used for land-management decision-making, engineering design, in the search for mineral resources, and for scientific research. Traditionally, geologic information has been stored and disseminated using geologic maps and written reports (Bernknopf et al., 1993). Because of the complexity of the earth, much of the information included in a geologic map is buried in several layers of abstraction. Production of derivative maps designed for a specific purpose thus requires a geologically sophisticated analysis of the original map and the drafting of a new map designed to depict a different aspect of the geology. Such maps might be designed to show rocks of a particular age, show the lithology of the rocks without respect to age, show the orientation of bedding or foliation in layered rocks, or to show the acid buffering capacity of the rocks, etc. Modern data storage and communication technology has created an opportunity to rethink the manner in which geologic information is archived and presented. This report discusses some ideas for the conceptual schema of a computer-based geologic information system.

This system will need to meet the needs of land managers or planners needing information pertinent to regulatory, planning, and development functions, mineral exploration geologists, researchers in search of detailed technical information, and curiosity-driven users from the general public. Many of these users may not be expert geologists, but still need to be able to query the system to obtain information. The underlying data model must be flexible enough to encompass a wide range of earth science information, storing it in such a fashion that it does not become obsolete with advances in geologic science.

As a starting point, it is useful to consider a fantasy view of the product. The ultimate geologic information system would contain a detailed 3-dimensional model of the Earth. Such a description would include:

* quantitative descriptions of the chemical composition of all materials

* quantitative descriptions of the physical characteristics of materials at any scale

* a classification of the materials into lithostratigraphic, biostratigraphic, and chronostratigraphic rock units (or material bodies).

* P-T-t paths for points throughout the model,

* descriptions of the static geometry and kinematic history of structures

* dynamic descriptions of active tectonic processes

* the geologic history of all rock bodies

The ultimate interface to such a system would allow natural language queries couched in technical or nontechnical terms, and respond by providing appropriate natural language answers, data tables, standard format output files, or visualizations (maps, cross sections, 3-D views, etc.). Knowledge of the physical location and structure of the stored data would be unnecessary to the user. Multiple working hypotheses would be stored for regions in which knowledge is incomplete or inconsistent. The origin of any particular fact or interpretation could be traced to its source. The system will play the role presently filled by geologic maps—providing information in response to queries, checking consistency of data to be introduced into the system, and archiving data for future use. The flexibility of a computer-based system provides for a much more complete description of the Earth in a form that permits more sophisticated analysis, and can be user-customized to meet particular needs.

Meanwhile, back in the real world of incomplete knowledge, limited budgets, and existing computer software/hardware environments, the geologists of today need to lay the groundwork for the data archive and analysis system of the future. Standard engineering procedures for system design begin with a requirements analysis. Without going into detail, the desired geologic information system must: 1) allow geologists to archive earth science data and interpretations in a logically consistent form; 2) track data sources and updates to the data archive, and 3) provide applications that query, retrieve, and display existing geologic information to meet the needs of environmental, engineering, exploration, and research geoscientists. The full information system thus consists of a data repository and a set of applications (interfaces) specific to particular fields of enquiry. The data repository subsystem consists of a data model to organize information, applications (methods) to track updates and maintain data integrity, and the physical data storage implementation. This paper is concerned with the design of the data repository data model for a geologic information system.

The design of the data model begins with development of a conceptual model that describes earth science (the universe of discourse) at a fundamental level using earth science terms and concepts. The purpose of developing a conceptual model is to provide a consistent framework for developing logical and physical models couched in database-system terms and concepts. These guide implementation of the information system in a particular computer environment. It is difficult or impossible to transfer data between information systems based on models with inconsistent underlying concepts. For example, if rocks were thought of only in terms of their whole-rock chemistry in one model, there would be no unique way to convert data stored in that model into one in which rocks were modeled as aggregates of minerals.

The following sections analyze two key sub-domains of earth science, geologic maps and lithology, and proposes conceptual models for some aspects of these domains. The appendices include a glossary of terms used, a discussion of the philosophy of conceptual modeling, and a review of some existing data modeling efforts relevant to the development of a geologic information system.

DOMAIN ANALYSIS: DESCRIPTION OF THE EARTH

The Earth is a composite object with a shape defined by solid matter (this discussion is limited to a static model). It is composite because it consists of many definable parts. Its shape is a spheroid defined by the solid matter of the lithosphere. The complexity of the Earth is qualitatively similar no matter what the scale of observation—TEM, microprobe, thin section, hand sample, outcrop, quadrangle, province, continent, planet. For any scale of observation, heterogeneity at smaller orders of dimensional magnitude can be averaged, and heterogeneity at larger orders of dimensional magnitude is outside the domain of interest. Thus, any model for describing the Earth must be hierarchical and recursive. A part of the Earth characterized by average properties at one scale can be analyzed into component parts (with different averaged properties) at a more detailed scale. The description is recursive because some parts of a material might be materials defined at the same level in the hierarchy. For example, the parts that make up a conglomerate (a rock type) are other rocks, maybe even fragments of a different conglomerate.

In this discussion, the smallest scale of observation considered is the hand sample—that is pieces of rock the average person can hold in their hand and examine with a magnifying glass. Generally this means that aggregates of particles smaller than about 0.1 mm are represented by average properties, and particles larger than about 10 cm are entities. The next scale considered is the outcrop—the average size of exposed rock that can be examined and described at one time, say 10 cm to 100 m. Map scale is taken to encompass 100 m to 100 km, and is the largest scale of observation considered here. The next larger 'spatial domain' might be called province scale, encompassing description of bodies with dimension 100-10,000 km.

Geologic descriptions can be associated with a point of observation, or can be a generalized description applied to a surface (fault, contact...) or rock volume (rock unit, region on a map, Formation...). For most of the commonly described geologic features, there are systems of classification based on certain characteristic features. Rock and fossil names are examples of such classification systems. A contact between rock bodies may be described as intrusive or depositional, connoting certain features of the contact. Many observations made by geologists in the field are summarized by identifying an observed object as a member of a predefined class. Such descriptive 'data' is subjective because assignment to a class depends on the classification system chosen and the experience of the geologist making the observations.

Part of the geologist's work in mapping an area is developing a system of classification for rocks, contacts, and structures that summarizes observations and simplifies the task of describing the variety of things observed. Some of the observed things will match criteria for standard geologic classifications or classifications developed in nearby areas. When something can not be matched to satisfaction with a known type, a new classification is defined based on observations in the map area. The definition must include a set of necessary and sufficient conditions to assign membership to the class, and place the class within the existing hierarchy of known things. Recording a full description of the classification system used to pigeon hole observations is an essential part of making a geologic map.

The Glossary of Geology (Bates and Jackson, 1987) defines 'rock' as an aggregate of one or more minerals, or a body of undifferentiated mineral matter (e.g. glass), or of solid organic matter (e.g. coal). This definition is modified slightly here to define a rock as a <u>consolidated aggregate of *constituent* parts, or a solid body of undifferentiated mineral or solid organic matter</u>. The constituent parts of a rock may be minerals or other rocks (as in a conglomerate). A simple rock consists of an aggregate of distinct mineral grains (granite). More complex rocks may consist of aggregates of rock fragments (conglomerate, breccia), or mixtures of distinct lithologic components (migmatite, gneiss).

The system of hand-sample description proposed here for use in computer databases is based strictly on features visible in the hand sample that are descriptive and nongenetic. Bates and Jackson (1987) define lithology as the physical character of a rock. In this report the term lithology will be modified by terms indicating the scale of description, and will refer only to rock-volume characteristics. The hand-sample scale classification scheme for Earth materials makes a first order distinction between consolidated and non-consolidated materials to separate rocks from other materials. For rocks, the highest level distinctions are made between aphanitic and phaneritic rocks and between rocks for which the origin can be determined based on features visible in hand sample and rocks of indeterminate origin. Further refinement of the lithologic nomenclature is based on five independent (orthogonal, unrelated) characteristics of the constituent parts, either individually or in combinations. These characteristics include grain size, grain shape, grain sorting, grain composition, and fabric (the relationship between the grains). Examples of a lithologic type based on each of these characteristics are sandstone, breccia, porphyry, hornblendite, and schist. The description of a complex hand sample might include descriptions of several lithologic components, each consisting of distinct assemblages of minerals with distinct fabrics, and a set of relationships between these lithologic components.

Standard lithologic nomenclature is based first on determination of origin—igneous, sedimentary, or metamorphic. In some cases, particularly for very fine-grained or altered rocks, this determination requires some information about the context of the rock. The restriction to features visible in a hand sample requires descriptive terminology to allow for situations where the rock origin is indeterminate.

In more detail, the first order classifications in the descriptive lithology system are:

1. Degree of consolidation (consolidated or non-consolidated).

Consolidated is taken to mean that a piece of the material can be held in the hand as a single mass, and does not disintegrate into its constituent parts if struck with a hammer. The importance of this distinction is to separate materials for which necessary and sufficient definition may include criteria based on intergranular aggregate properties (e.g. sandstone) from those for which the definition must be based solely on the nature of the constituent particles (e.g. sand). Clearly there is a continuum from non-consolidated to consolidated (e.g. gravel in an active stream to conglomerate, or laterite to underlying granite), but to be useful for a computer database, a material must be one or the other. A non-consolidated deposit may form an outcrop (e.g. a trench to expose a soil profile), and can then be described in terms of outcrop-scale lithology. For hand sample lithologic description, a material is either a rock (consolidated) or a non-consolidated material.

2. Degree to which constituents can be discerned (aphanitic or phaneritic).

Rocks that have discernible constituents can be described in terms of those constituents. If the material is aphanitic (constituents not discernible, i.e. diameter <~0.2 mm), it is homogeneous for our purposes, and belongs to the undifferentiated mineral matter and solid organic matter types mentioned in the definition of rock. Phaneritic rocks are classified based on the nature of the parts that make the whole, and the relationship between the parts.

3. Genetic origin (sedimentary, igneous, metamorphic, composite, anthropogenic, or indeterminate)

The third criteria separates material for which generic names must be used from those for which the standard igneous, sedimentary, and metamorphic rock terminology can be used. Rocks with features that demonstrate crystallization or cooling from a melted liquid are igneous. Rocks with features that demonstrate formation of the rock at low temperatures and pressures at or near the earth's surface are sedimentary. Conceptually, a metamorphic rock has a composite origin, but for consistency with standard practice, metamorphic is considered to have the same rank as igneous, sedimentary, and anthropogenic. The composite origin type includes rocks containing features indicative of a polygenetic origin that are not metamorphic rocks. The composite origin type includes various problematic rock types. Volcaniclastic rocks are commonly not clearly of uniquely sedimentary or igneous origin. Composite rocks also include metasomatized (hydrothermally altered) and weathered rocks that are different enough from their original character to merit a new classification, but are not typically thought of as metamorphic. Anthropogenic Earth materials are those that are the product of human activity. Since this classification scheme is designed to be descriptive, the criteria to distinguish these various types must be based on features observable in a hand specimen. If no such features can be observed, the rock origin is indeterminate.

This schema for defining lithology can be extended to describe the Earth at larger scales. An outcrop description consists of a collection of lithologic components (hand-sample scale) and descriptions of the relationships between the components. At the outcrop scale, the orientation of geometric elements of the fabric (in the Earth reference frame) is introduced as a feature of a complete description. The terminology for this scale of observation probably corresponds more closely to familiar geologic usage, because it allows for more genetic nomenclature based on context. A map-scale description consists of a collection of map units (rock bodies) defined based on generalization of outcrop-scale description, and descriptions of the nature, location, and orientation of boundaries between the units (analogous to fabric on smaller scales). This description schema can be applied to stratigraphic sections, formations, groups, supergroups, terranes....etc.

The boundaries that separate rock bodies from other rock bodies are geological surfaces. A geologist studies the characteristics of these surfaces to infer the relationships between rock bodies. In detail, geologic surfaces are normally boundary layers of finite thickness. For example, a fault might have a breccia zone of a particular thickness, and a gradational contact has a characteristic thickness between what is clearly rock A and clearly rock B. The boundary layer thickness limits the precision at which that surface can be located. At contacts between rock bodies, one rock will in general be older than the other. Exceptions include boundaries between metamorphic or alteration zones and facies boundaries. A fault surface has an associated vector field that represents the slip on the fault at each point on the surface. Faults also have bracketing ages for time of movement. Geologic surfaces thus have intrinsic properties of direction, thickness, and time.

A geologic map is a complex knowledge representation. A standard geologic map depicts the location of rock body boundaries as lines that bound closed polygons. The polygons are colored or labeled to indicate the geologic map unit that is found at (or below!) the Earth's surface at points within the polygon. The system used to classify earth materials into the map units is described in accompanying text. The map units are often defined in terms of geologic formations that are only described in a cursory fashion with reference to technical literature that provides more complete information. On many maps the description of the classification system is such that a user who does not have a strong background in geology would have difficulty answering simple questions about the materials that might be expected to be associated with the outcrop of the map unit.

An important concept in analyzing the information contained in geologic maps is the distinction between a description of a rock volume, and a description of a surface. Rock units describe the characteristics of a volume of rock. Surficial geologic units describe the characteristics of the boundary layer between solid earth and atmosphere or hydrosphere. Surficial units may describe the lithology of deposits to a depth that is small relative to the horizontal extent of the map, or may relate to surface morphology, age (as opposed to deposit age), or depositional environment. The colored polygons on a geologic map either represent the intersection of rock volumes with the earth's surface (or map horizon), or represent characteristics of particular regions of the earth's surface (or map horizon). To a geologist interested in the processes and characteristics of the earth surface, the lines on the map represent boundaries of closed regions in the surface. Faults and rock-body contacts on a geologic map represent the intersection of two surfaces (rock body boundary and earth surface), projected onto a 2-D map surface. A geologist interested in the rock bodies that compose the earth beneath the map surface uses the 3-D geometry of these intersection lines, along with measurements of surface orientations noted on the map, to understand the 3-D model of the earth depicted by the map.

This 3-D analysis requires significant prior knowledge of geologic map interpretation. Classification of contact types on geologic maps is generally binary-'fault' or 'contact'. Geologic reasoning must be used to determine the relationships between rock bodies. For example, consideration of rock type (e.g. granite), and rock age for adjacent rocks allows geologists to identify a contact as a conformable depositional contact, nonconformity, angular unconformity, or intrusive contact. Accompanying text sometimes describes the nature of contacts that do not conform to any simple classification. The geometry of faults and contacts is either encoded on the map using a symbol (dip-direction arrow and dip magnitude), or it must be extracted by analyzing the location of intersection points between the contact trace and topographic contour lines. The geometry of faults and contacts can then be used to determine underlying and overlying relationships not described in the map legend. Once the geometrical relationships of depositional and intrusive contacts are understood, the offset of intersection points of contacts at faults on the two sides of the fault for a series of contacts can be used to constrain possible magnitude and sense of displacement on a fault.

The classification of measurements of orientation of features (bedding, foliation, contacts...) shown on the map is generally indicated by a set of symbols representing standard feature types, with little or no explanation of the criteria used to assign membership to a particular class. In areas of complex structure, much of the orientation data collected in the field is not shown on the map because of space limitations. The printed geologic map thus contains a great deal of information that is not explicitly stated, and probably contains only a subset of the data and observations made by the geologist in the field. This data can be recorded in a usable form in a computerized map database.

A geologic map is a visualization of the geologist's knowledge about the spatial distribution of rocks and the relationships between them in a particular area. The steps to produce this visualization are:

1. Select a map horizon.

This is the surface that contains the physical features to depict. It may be any arbitrary surface within the earth, but most commonly is the actual earth's surface on which geologic observations are made.

2. Define the extent of the region in the map horizon to depict

3. Select a set of geologic entities to depict. These may be rock volume or surface objects.

4. Determine the intersection of these volumes and surfaces with the map horizon.

If the map horizon is non-planar (e.g. the Earth's surface), this procedure will produce bounded 3-D surfaces and 3-D lines. A surficial geologic map is a special case in which the geologic surfaces to depict are identical with the map horizon, in this case the Earth's surface. Other sorts of surface maps might show the distribution of fault rocks in a fault surface, or the distribution of alteration and mineralization along a vein.

5. Project the 3-D surfaces and lines from earth coordinates on the map horizon to map coordinates in a planar surface.

If the map horizon is planar (e.g. a cross section or mine-level map) this step only requires scaling. This results in a map consisting of lines and polygons that represent the intersection of the geologic entities of interest with the map horizon, or the extent of geologic surface entities on the map horizon. These lines and polygons are cartographic entities.

6. Symbolize each cartographic entity.
Assignment of graphical elements is based on the classification of the geologic volume or surface entity represented by the cartographic entity.

7. Superimpose the geologic map on a base map.
The base map supplies the geographical context necessary to relate the geologic relationships to the real world. If topographic information is included on the base map, the 3-D geometry of geologic lines on the map can be deduced to provide a basis for interpretation of the 3-D geometry of rock bodies.

One of the attractions of a digital geologic database is the possibility of including a record of as much information as there is time or need to record about an area. The geologic data model must facilitate the storage, retrieval, and analysis of information at whatever level of detail it is available—whether the information is from detailed field notes or a 50-year old reconnaissance map. System-specific software tools based on the model would allow users to produce derivative maps tailored to their needs, showing things like distribution of rock containing more than 50% quartz, distribution of white rocks, distribution of fine-grained rocks, or all steeply dipping faults.

CONCEPTUAL MODELS OF SOME GEO-SCIENTIFIC ELEMENTS

In this section, some aspects of the earth science domain described in the previous section are modeled using the Object-Role Model (ORM) formalism (Halpin, 1995). This formalism was chosen because it is expressive enough to describe the necessary concepts, and techniques are available to implement an ORM conceptual model with relational database software. Figure 1 summarizes the notation and concepts used to graphically depict conceptual models presented below. The domain of discourse to be modeled must be separated into sub-domains to make the graphical depiction more comprehensible. Models for two general purpose sub-domains are presented first. These are Scalar Quantity and Fractional Analysis. The geologic sub-domain models included here are Lithology Type, Particular Lithology, Constituent Geometry, and Geologic Surface. These models assume the existence of a standard classification table (analogous to the COA of Johnson et al., 1998) that contains definitions of standard classification types. Entities referenced to this table are shown as values with a reference to 'ClassID'. All of these models are draft versions that are still under development.

General Purpose Sub-domain Models

Quantities are most often used to represent measurements. They can be scalar (magnitude of magnetic field, isotopic date from a rock...), unit vectors (orientation of surfaces...), vector with magnitude (slip vector for fault, gravity or magnetic field...), or arrays (cobble counts, fracture orientation distribution...). These measurements serve a wide variety of purposes, but are generally associated with a point or area with small dimensions relative to the map scale. The values obtained for these features ideally are independent of the observer collecting the data.

Scalar Quantities (Figure 2) are used throughout the model to specify numerical values. The **Scalar Quantity** concept modeled here allows several representations. The simplest is 'quantity has a single numeric value and a measurement unit attribute'. Possible more complex representations include a single value with an uncertainty, or a minimum and maximum value with a specified default value to use if a single value representation is required. In all cases the **Scalar Quantity** has a specified unit of measurement attribute. Subtypes of **Scalar Quantity** in other Figures are identified by the use of QuantityID as the reference mode for a subtype entity.

The **Fractional Analysis** (Figure 3) concept is used to model any situation in which an entity is composed of other entities in certain proportions. Common examples are chemical analyses, grain size-distributions, and modal mineralogy. Constituent types used in Fractional Analyses are specified in a system classification table. Constituents that are used as fractional parts of a described entity must be allowed as components of a **Fractional Analysis** of the Described Entity. If the quantity that specifies a fraction of some constituent is specified as a range **Scalar Quantity**, an algorithm is necessary to adjust default values so that the constraint "sum of fractions = 1" can be met. When a constituent is added in the analysis, a check must test that the sum of the minimum value for all the fractions is <= 1, and that the sum of the maximum value is >= 1. These checks ensure that "sum of fractions = 1" is possible. If the sum of the fractions for constituent parts is <1, the difference is automatically classified as an unspecified constituent. **Fractional Analysis** entities appear in **Particular Lithology** schema (Figure 5) for Chemical Composition, and in the **Constituent Geometry** schema for Grain Size Distribution.

Geologic Sub-domain Models

Two schemas are presented to model the concept of lithology. The **General Lithology** schema (Figure 4)

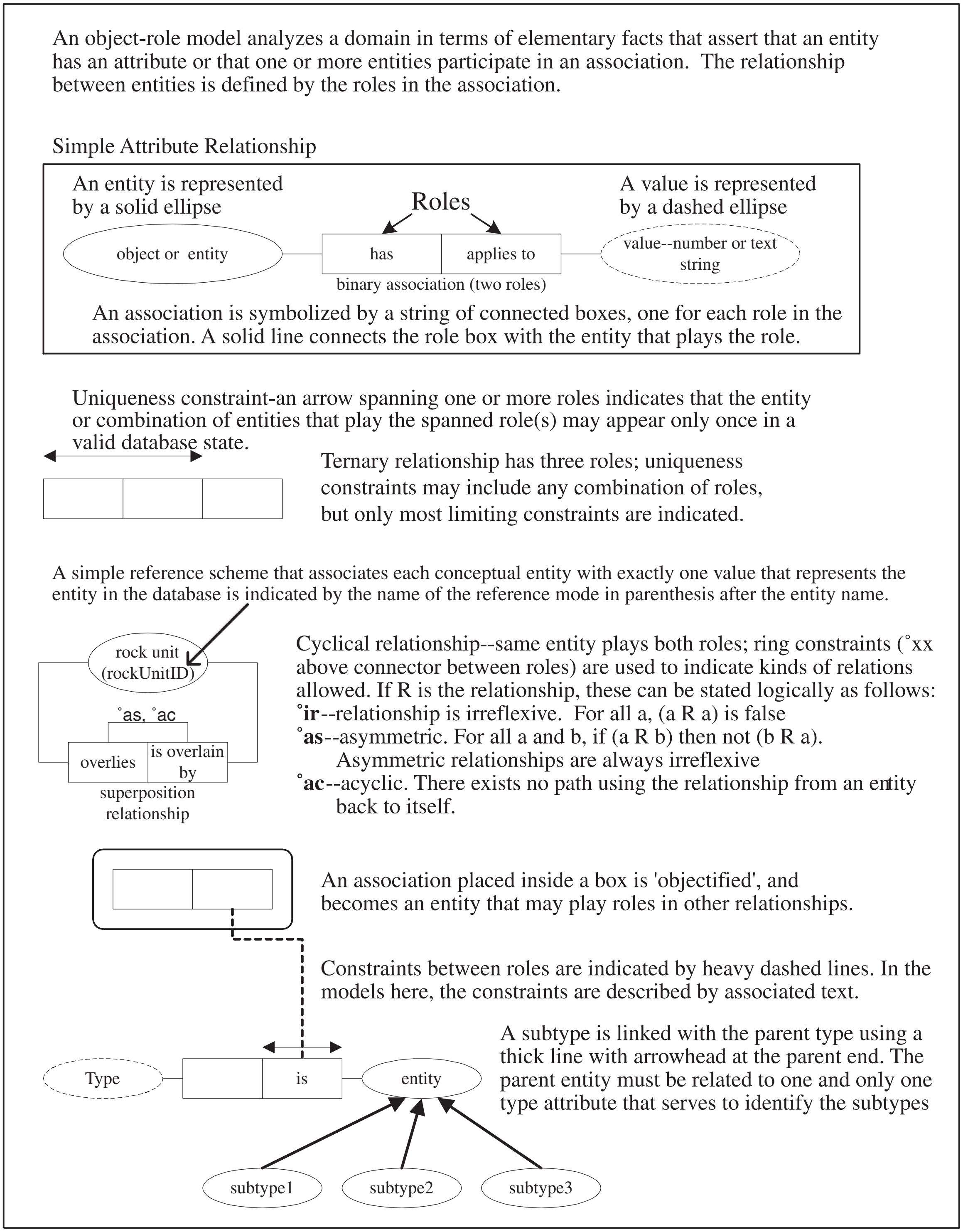

Figure 1. Overview of Object-Role Model (ORM) graphical notation and conventions.

models the structure of a lithology type definition. These definitions provide the logical foundation for classification of rocks into general lithologic classes. A geologic information system should contain a basic set of clearly defined lithologic terms in a standard classification table. This schema closely follows the description of lithology in the Domain Analysis section (above). The **General Lithology** may have widely varying degrees of specificity. The most general types are defined on only one aspect of the lithology—e.g. sandstone, mudstone, schist.

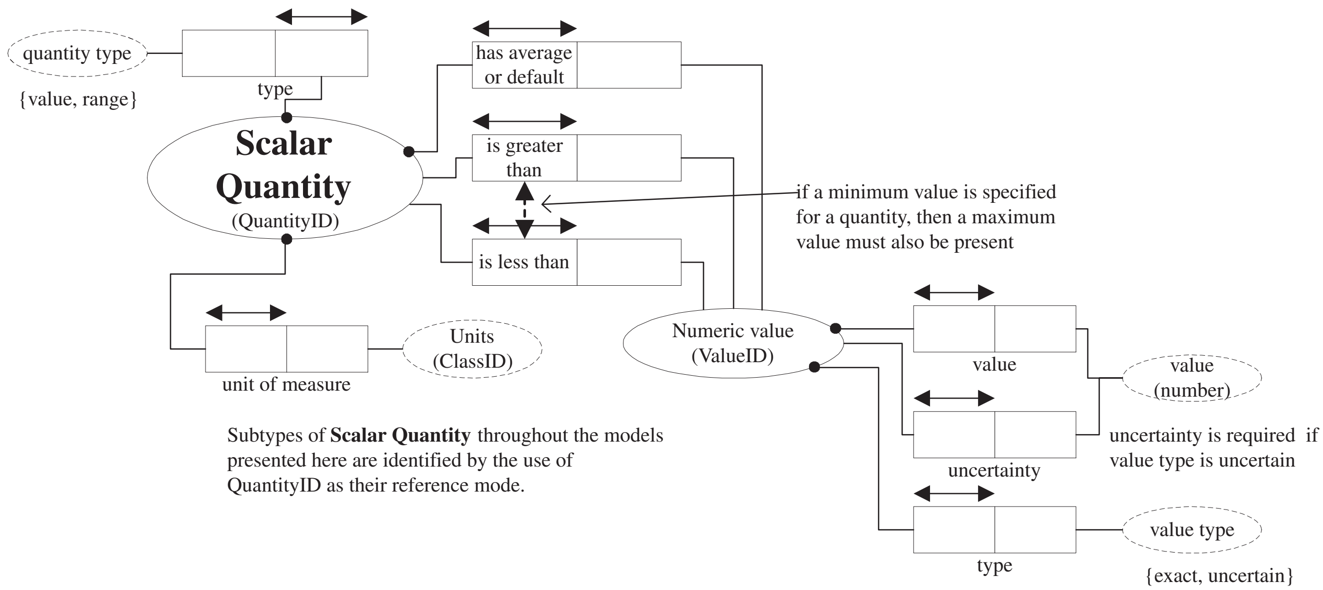

Figure 2. Schema for Scalar Quantity.

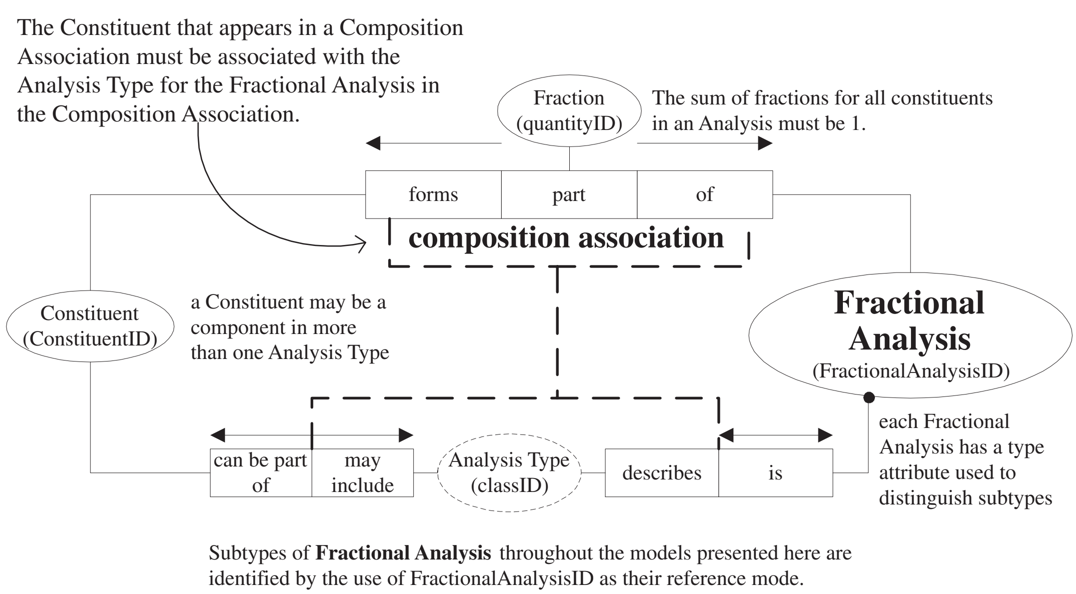

Figure 3. Schema for Fractional Analysis.

The **Particular Lithology** schema (Figure 5) models the description of a particular rock. The information system should include a set of idealized 'typical' **Particular Lithology** entities associated with each **General Lithology** to provide default values for characteristics not specified in the **General Lithology** definition. The **Particular Lithology** entity will also be used for the description of rock hand samples. A **Particular Lithology** is modeled as an aggregate of Constituents. The Constituents may be Mineral or other Particular Lithology entities, allowing for recursive description. Each Constituent may be involved in one or more Relationship_within_Whole associations (see Table 1 for examples) with the **Particular Lithology**. For each role a Constituent plays in the aggregate, a **Constituent Geometry** can be described (Figure 6). This includes aspects such as grain size, grain shape, and sorting for a particular Rock Constituent playing different roles, e.g. as groundmass or as phenocrysts. Relationships between Constituents in particular roles within the whole aggregate

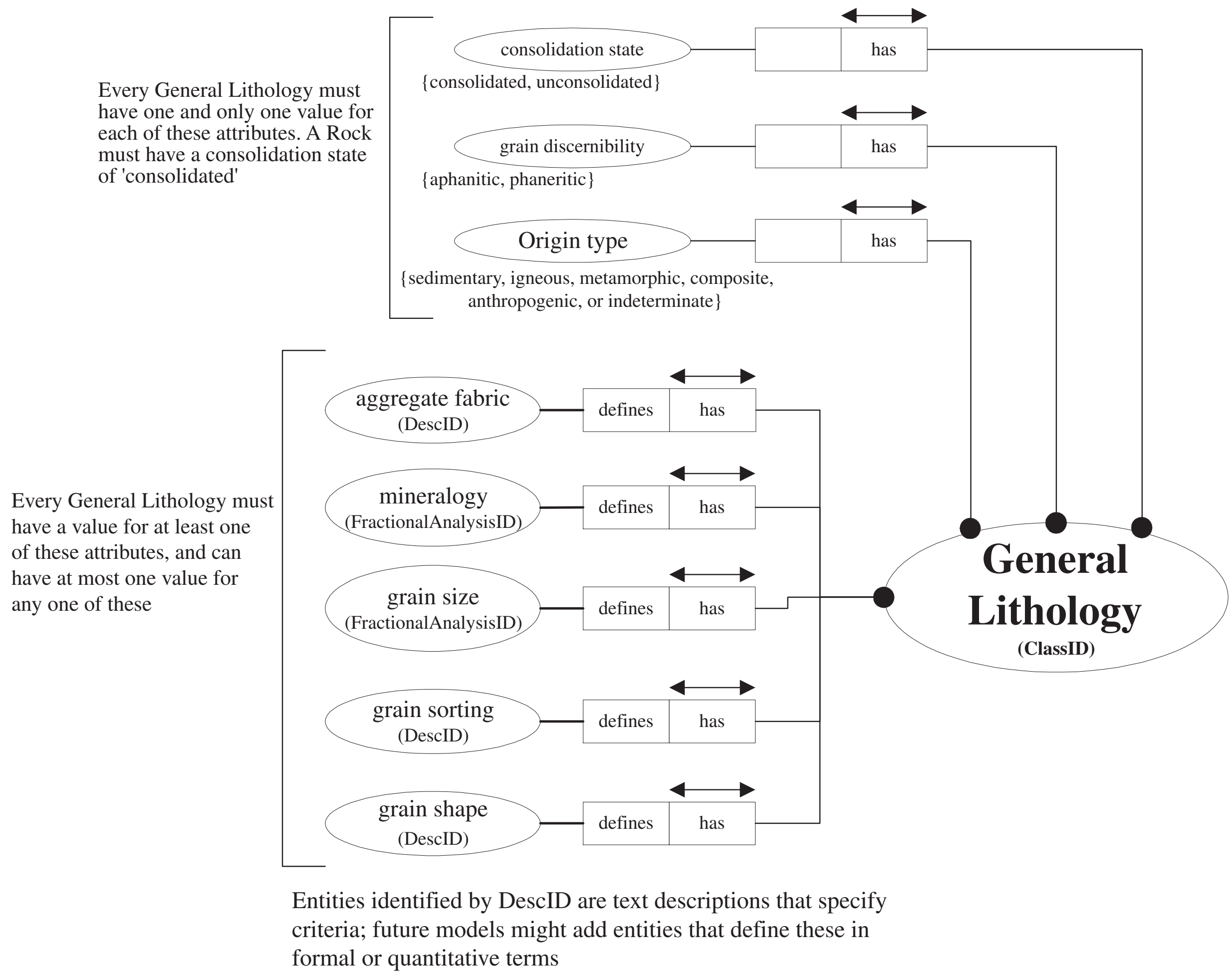

Figure 4. Schema for General Lithology

are described by Relationship_between_constituent associations (Table 2). These associations define the hand-sample scale fabric and structure of the rock. A Mineral or a **Particular Lithology** may have physical property attributes such as color, density, magnetic susceptibility, sound velocity, and refractive index. Chemical Composition is a subclass of **Fractional Analysis** (Figure 2), and may be associated with a Mineral or a Particular Lithology.

Table 1. Examples of Relationship_within_Whole associations

Forms matrix in
Defines schistosity
Defines graded beds
Forms phenocrysts in
Forms porphyroblasts in

Table 2. Examples of Relationship_between_Constituent associations:

Replaces
Forms a rim on
Crystallized before
Interstitial to
Enclosed in

Constituent Geometry (Figure 6) models a data structure for describing the geometry of individual constituents in a **Particular Lithology**. These descriptions are based on terms that may have qualitative or quantitative definitions (e.g. round, subround, euhedral, subhedral, fine-grained) or on free text descriptions referenced by 'descID'. The **Constituent Geometry** description has two

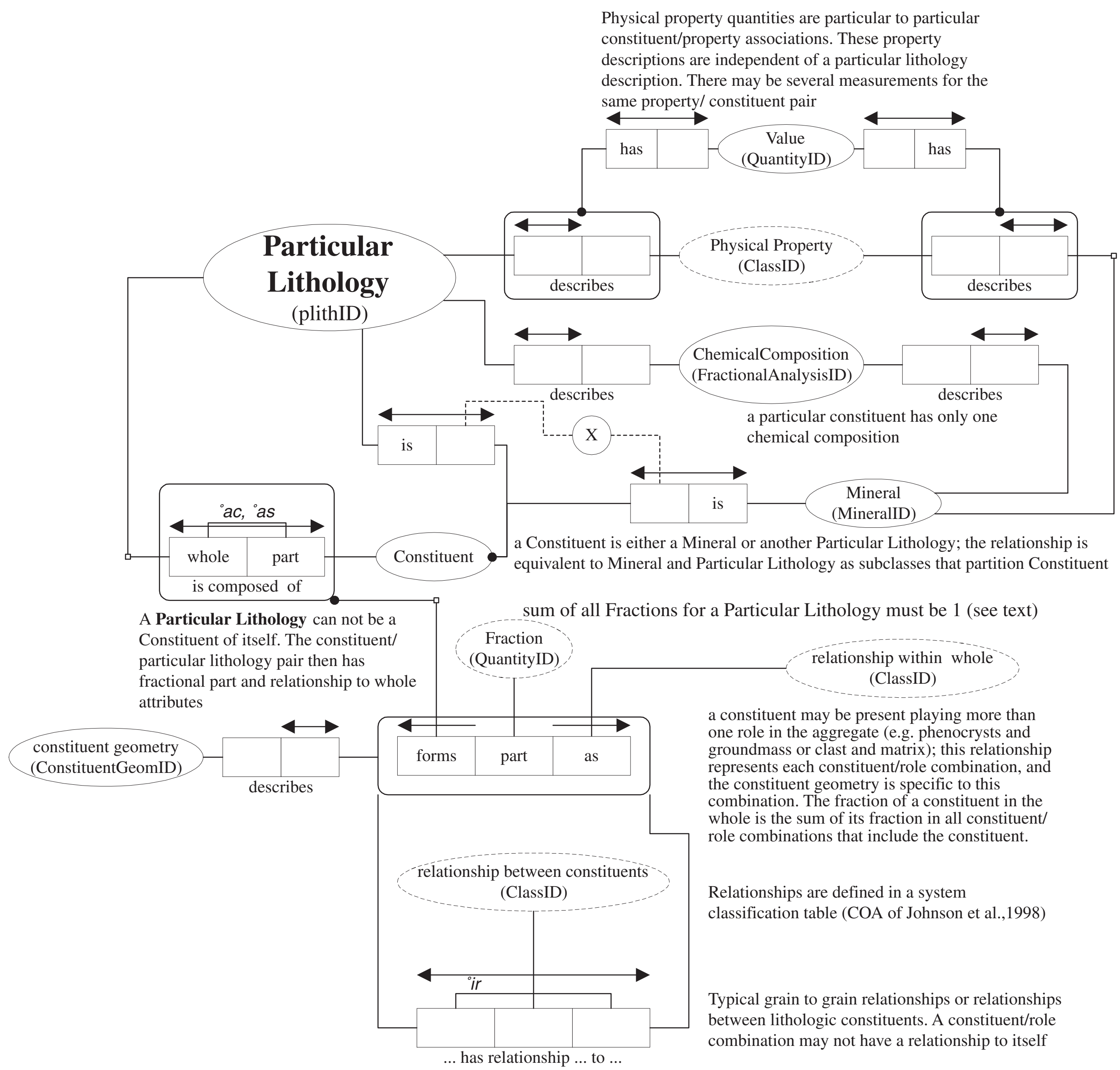

Figure 5. Schema for Particular Lithology.

sub-classes, Grain Geometry and Body Geometry, because different terminology is used when describing individual grains or lithologic components in a mixed rock.

The **Geologic Surface** (Figure 7) schema requires that a Geologic Surface have a type attribute that determines the subclass membership for the surface, and an attribute that indicates if the surface is directed. A characteristic Thickness of the surface may also be defined. Fault surfaces have associated Slip Vectors that record displacements across the fault. A Fault may have several associated slip vectors if displacement is known to have changed over time. Faults and Contacts both have associated Age Ranges. For a Fault, the age range is the time interval during which the fault was active. For active faults, the lower bound of this range is 0. Faults may have more than one associated age range to allow for more than one period of activity. Distinct age ranges may be related to distinct slip vectors to record the full displacement history of a Fault. The age range associated with Contacts represents the time interval that separates rocks on either side of the Contact. Only one age range may be associated with a Contact. Degenerate Volumes are entities used to represent descriptions of a discrete layer or a boundary layers that is too thin at the scale of representation to depict on a map. Examples include soil profiles, dikes, veins, fault rocks, and marker beds. A Degenerate Volume surface is associ-

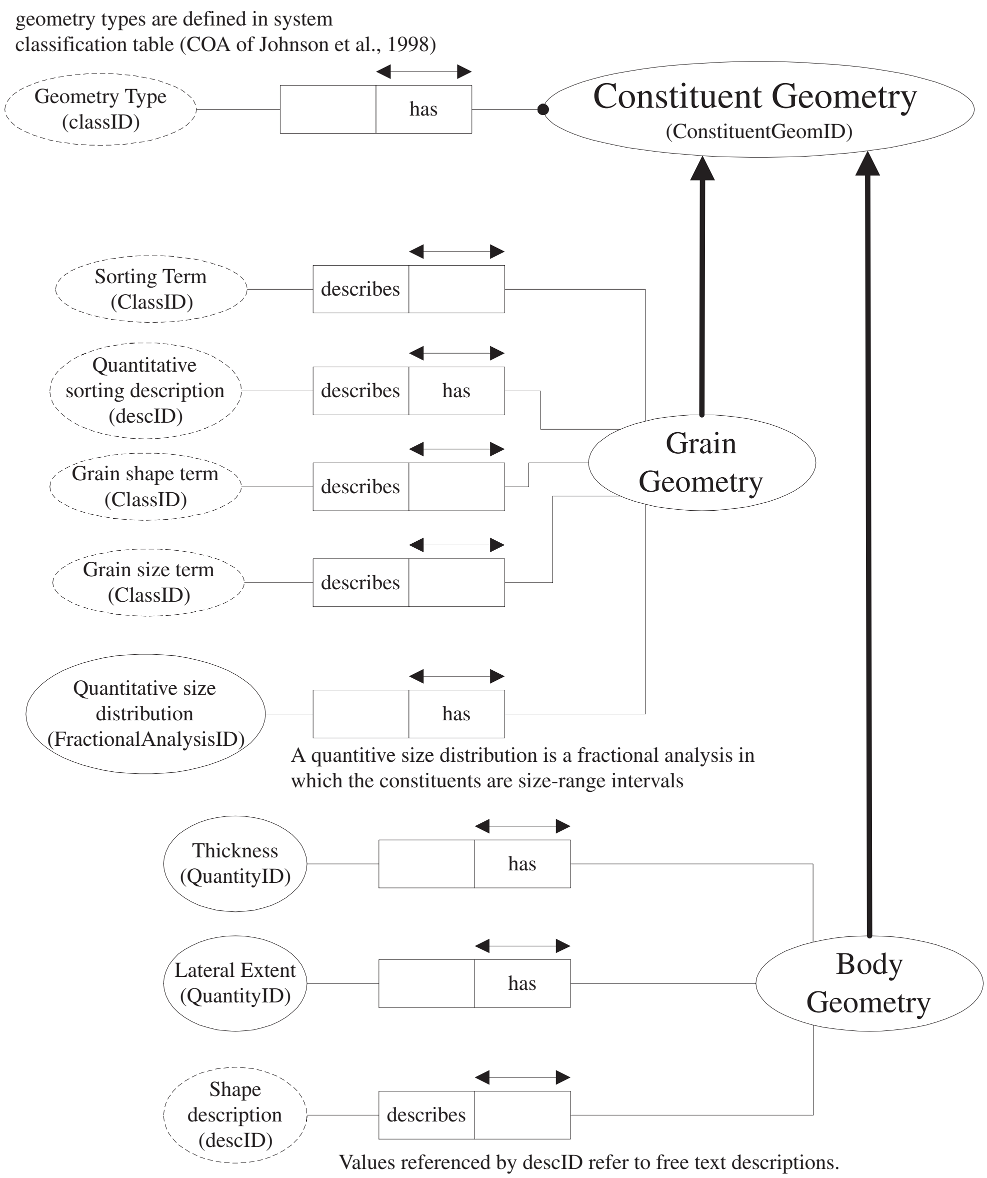

Figure 6. Schema for Constituent Geometry.

ated with a Rock Unit classification object that describes the lithologic characteristics of the material in the boundary layer. A thickness must be defined for a Degenerate Volume surface.

CONCLUSIONS

This paper presents some simple conceptual models for a small subset of the Earth Science domain of discourse. Such models are an important precursor to implementation of a large-scale database by formalizing the concepts used to represent the domain of discourse. The models presented here are by no means complete, and have not been tested against large sample data populations. The process of developing these models has led to the recognition of many unforseen conceptual difficulties, and has led to the revelation of a compositional hierarchy data structure that serves to describe many aspects of the domain. My own experience developing these models has convinced me of the importance of this step in the database design process.

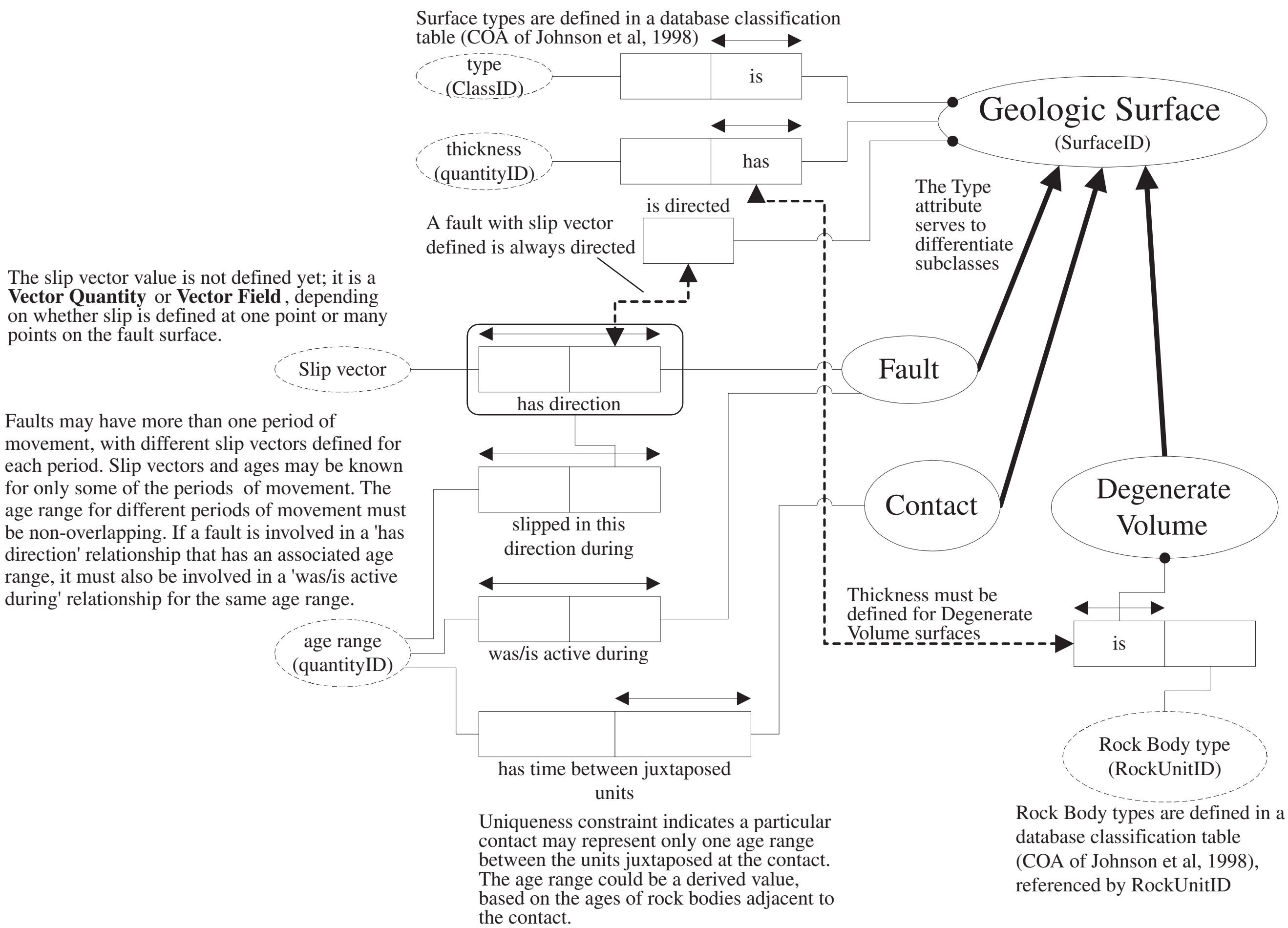

Figure 7. Schema for Geologic Surface.

APPENDIX A. GLOSSARY

Some definitions are presented to clarify the terminology used here.

Association: A concept that defines what a thing has to do with one or more other things. An association has no independent existence (Angus and Dziulka, 1998). Associations corresponds to logical predicates (Halpin, 1995).

Attribute: An inherent characteristic (Merriam-Webster Dictionary, 1999)

Class: A set of things sharing common attributes, defined by a set of criteria (a type). (Angus and Dziulka, 1998).

Collection: A contingent aggregate of things, interpreted as an individual (Allgayer and Franconi, 1994).

Concept: A general idea, derived from specific instances or occurrences (American Heritage Dictionary, 1982). An abstract or generic idea generalized from particular instances (Merriam-Webster Dictionary, 1999)

Domain: The collection of things that may exist in a particular model.

Entity: A thing that has independent, separate, or self-contained existence (Merriam-Webster Dictionary, 1999). An instance of a type that has its own identity and can be distinguished from another instance that meets the definition of the same type. This implies that an entity has an additional property that is its unique identifier.

Instance: A thing that is representative of a type (American Heritage Dictionary, 1982). An instance does not have a unique identity (compare to entity); two instances representative of the same type can not be distinguished (Angus and Dziulka, 1998).

Individual: A single thing in a domain (Allgayer and Franconi, 1994)

Primitive Concept: A concept that has no internal structure or cannot be defined in terms of necessary and sufficient properties (MacRandal, 1988).

Relationship: A connection between an association and a thing. The relationship is identified (with respect to the association) by the role played by the related thing in the association (Angus and Dziulka, 1998).

Role: The thing that receives or is affected by the action of an association. A concept that indicates in what capacity some thing is involved with some other thing. Roles are used in naming relationships with respect to an association (Angus and Dziulka, 1998). Roles hold information about function.

Specific Thing: An individual occurrence of some thing; an entity (Angus and Dziulka, 1998).

Taxonomy: A superclass/class/subclass hierarchy in which every instance of a child class is a member of the class(es) that are parent of the child.

Thing: An entity, situation, association, or event that may be perceived, known, or imagined.

Type: The semantic distinctions between 'type', 'class', and 'domain' are ambiguous and inconsistently applied in the literature. Type here will be taken to apply to the set of attributes that determine, for any thing, whether that thing is or is not a member of a class. A type defines a domain; a class is a set of things that belong to the domain. The domain is the abstract collection of all things that meet the definition of the type. Instances of types do not have an identity, i.e., two instances of the same type can not be distinguished (definition distilled from many sources).

Typical Thing: A type based on a particular set of entities, characterized by a subset of the attributes of the real world entity(ies), and/or idealizations of those attributes. Attribute values are assigned, not measured, and are normally specified as a possible range of values (Angus and Dziulka, 1998).

APPENDIX B. DATA MODELING

This section is a review of data modeling literature and activities that provide a context for efforts to develop a USGS/AASG geologic map data standard (Johnson et al., 1998). In order to communicate knowledge about a particular domain, there must be some agreement on the concepts and roles defined in that domain. This common framework of concepts and roles is called a conceptual model for the domain in question. Much research into conceptual models, or knowledge representation, has taken place in the artificial intelligence arena. These efforts are important to geoscience data modeling because they attempt to formalize systems for describing the real world. Such systems are necessary to consistently map geologic knowledge into logical models that can be implemented in computer databases. The most common approach to modeling descriptive knowledge of the sort recorded on geologic maps is based on the idea of a structured inheritance semantic network (Brachman and Schmolze, 1985; Ringland and Duce, 1988). There are other models for knowledge systems, but this approach is used here because it lends itself well to implementation with current computer systems, and corresponds well to the thought processes used by geologists.

A semantic network is formed by defining a set of primitive concepts, or abstractions of fundamental things in the real world. Concepts are the things we can talk about, the epistemological primitives of our thought process. A primitive concept commonly corresponds to a 'natural kind'—something abstracted from the real world, that cannot be defined logically in terms of necessary and sufficient conditions. A partial definition of a primitive concept can include necessary conditions. Derived concepts are defined by logical combination of concepts, or association of a concept with attributes and constraints to identify a subset of the concept. An association is an ordered pair of concepts and a predicate that defines the role of the association. The associations between the parts of a derived concept define the structure of the thing being modeled. A constraint is an association between parts of a derived concept that has a boolean value property whose value depends on properties of the instances of things it involves. For an instance of a concept to be valid, all its constraints must evaluate to true. In a semantic network, the concepts are represented as nodes, and the associations as connections between the nodes.

There is widespread interest in methods for developing and expressing data models, driven by efforts to automate various business operations. Recent contributions include XML-Data (<http://www.w3.org/TR/1998/NOTE-XML-data>), which is an extension to the Extensible Markup Language (XML) (<http://www.w3.org/TR/REC-xml>). XML-Data was designed to communicate information about the structure of data over the world wide web. This will allow applications to be produced that could acquire and analyze data sets from a variety of sources without prior knowledge of the data structure underlying the data set. The Universal Modeling Language (UML) (<http://www.rational.com/uml>) is a system for modeling the structure of data and operations necessary to utilize the data for a particular purpose. This language was motivated by efforts to provide a standard mechanism for describing complex data management operations, thereby facilitating the development of computer-aided software engineering (CASE) tools. UML is strongly based in Object-oriented system thinking. For a comparison of UML with the Object-Role Modeling approach used here see Halpin (1998).

Another important effort to develop tools for data modeling has been driven by the International Organization for Standardization (ISO) project 10303, *Industrial automation systems and integration, Product data representation and exchange* (referred to as the *International* ST*andard for the* E*xchange of* P*roduct Data* or STEP). As part of this project, a formal information requirements specification language, named EXPRESS, has been developed (Spiby, 1998). EXPRESS and UML appear to provide similar modeling capabilities.

In connection with the ISO 10303 project, a group named EPISTLE (European Process Industries STEP Technical Liaison Executive) has published a document titled "Developing High Quality Data Models" (West, 1996). This document discusses the rationale for a systematic approach to data models, and lays out a set of principles for developing data models that are stable, flexible to changing practices, and extensible to changing needs. These principles include:

* Candidate attributes should be treated as representing relationships to other entities
* Associations should be represented by entity types (not relationships or attributes)
* Relationships (in the entity/relationship sense) should only be used to express the involvement of entity types with associations.
* Entity types should represent, and be named after, the underlying nature of an object, not the role it plays in a particular context.
* Entity types should be part of a subtype/supertype hierarchy that defines a universal context for the model. The context is the range within which the model is valid. A data model also has a scope that encompasses what is actually modeled. If the context for the model is universal, then any extension to the scope will always be contained within the context.

The EPISTLE group has also published a Framework document (Angus, and Dziulka, 1998), that provides a high-level (meta) model and a set of core constructs that serve as a basis for deriving 'high-quality' conceptual models. I have attempted to incorporate the EPISTLE framework into the models presented here.

APPENDIX C. SURVEY OF RELEVANT DATA MODELS

Spatial Data Model

The OpenGIS consortium is attempting to develop a set of specifications to allow 'interoperable geoprocessing' (Open GIS Consortium Technical Committee, 1998). Part of this effort is a specification for conceptually representing the Earth and Earth phenomena. Discussions of the nature of the "National Geologic Map Database" (<http://ncgmp.usgs.gov/ngmdbproject>) commonly include consideration of the database as a set of resources distributed over separate nodes that may be operating in different software/hardware environments (Soller and Berg, 1997). The OpenGIS specification is being designed as a means of implementing exactly this sort of distributed spatial database. To the extent that this specification gains acceptance and software becomes available to implement the services required, this effort could provide the framework for developing a National Geologic Map Database that would conform to an industry standard. Conformance with such a standard would mean that the geologic community would not have to develop a lot of application-specific software.

Significant development of spatial data models in the specific context of earth science has also been necessary in the development of software applications for visualization of 3-D geologic models. The GOCad Research Program was initiated in 1989 by the Computer Science group of the National School of Geology (ENSG) in Nancy, France. The goal of this project is to develop a new computer-aided approach for the modeling of geological objects specifically adapted to Geophysical, Geological and Reservoir Engineering applications (c.f. Royer et al., 1996). The project is supported by an international consortium of oil companies and academic institutions. [For more information see web page at <http://www.ensg.u-nancy.fr/ GOCAD/ Welcome.html> and <http://www.ensg.u-nancy.fr/GOCAD /doc/ref_man.html>.] The documentation on the web site reports compliance with the POSC standard (see below). 3DMove (<http://www.mve.com/p-3dmove.html>) is a similar commercial software package developed for visualization of 3-D geologic structure, but no information is available on the underlying data model.

Geoscience Data Models

A great deal of effort has been made by the petroleum industry to develop a logical data model to facilitate the interchange of data. Two major initiatives have proposed models: Petrotechnical Open Software Corporation (POSC), and the Public Petroleum Data Model (PPDM). The POSC model is based to a large extent on the framework of ISO 10303 (STEP). Its scope includes technical and business aspects of petroleum exploration, development, and production (POSC, 1997). The complexity of the model is daunting, and the documentation provides only the basic information necessary to define the model. Study of the model suggests to me that it may provide nearly all the data constructs necessary for the purposes of the National Geologic Map Database, but more detailed analysis is necessary to determine if the conceptual models proposed here can be mapped into constructs in the POSC model.

Some problems with the POSC model have been identified. First, the model introduces 'named data types' that are outside of the data types defined in the EXPRESS language specification (Spiby, 1998). Thus, public domain software designed to interpret and edit conceptual models written in EXPRESS does not work with the POSC model. Second, the scope of earth science included in the model is limited to aspects relevant to petroleum exploration and production. There are no provisions for the complexities of igneous and metamorphic rocks, or for describing surficial geology, beyond those that overlap with the geology of sedimentary rocks.

The Public Petroleum Data Model is the second data model developed to standardize data modeling by the petroleum industry. Details of this model are available only to members of the association, and have not been studied by the author. More information is available at <http://www.ppdm.org/>.

A number of government geological surveys have developed models for internal use. These are documented to varying degrees. Workers from the British Geological Survey (BGS) have published a series of papers on geologic map database models, data dictionaries, and standardization of mapping practices (Laxton and Becken, 1996; Bain and Giles, 1997; Giles, 1997; Allen, 1997). The paper by Bain and Giles (1997) outlines the framework of the data model used by BGS using entity-relationship diagrams, but does not give detailed definitions of the entities used. This paper points out the importance of defining the mapping horizon (GEOLOGICAL LEVEL in their terms) as a proxy for elevation data associated with x,y points on a geologic map.

The Australian Geological Survey Organisation (AGSO) has been involved with geological database development since the 1970's, and is a participant in the POSC and PPDM efforts. Their system has apparently developed from the ground up, evolving into an integrated database system with the OZROX Field Geology Database at its center (Ryburn et al., 1995). OZROX contains information on field locations, outcrop data, measured section and drill hole logs, lithology and sample data, and structural observations. It is linked with databases for geochronology (OZCHRON), whole-rock geochemistry (ROCKCHEM) petrography (PETROGRAPHY), biostratigraphy (STRATDATA), the Australian national petroleum database (PEDIN), a bibliographic database for source citations (AGSOREFS), and standard reference databases for Stratigraphic Names, Geological Provinces and the Geological Time Scale. A published description of the conceptual model underlying OZROX has not been found.

AGSO arranged for the Australian Mineral Industries Research Association (AMIRA) (<http://www.amira.com.au/>) to contract the development of a standard geoscience data model across the mineral exploration industry. The AMIRA project P431, "Geoscience Data Model" was delivered in April, 1998 (Ryburn and O'Donnell, 1998), consisting of entity-relationship diagrams and a data dictionary. The model is described in Miller et al. (1998). It models the domains of geology, geochemistry, drilling, and mineral resource information. The model is designed to provide a standard database framework for mineral exploration companies to file required reports on their exploration activities with government agencies, and to facilitate data exchange between companies. It provides elegant data structures for storing information on boreholes, rock samples, mineral deposits (orebody geometry, commodities, production), geochemical analyses, and relationships between companies, exploration projects, and tenements (mineral leases). The model includes a 'profile' construct to provide metadata defining customized implementations of the full model. A conceptually similar 'template' construct provides metadata to describe sets of chemical analyses. Detailed geologic descriptions are included through fields for stratigraphic unit, rock type, lithological name, and lithological descriptor and text comments that may be applied to any 'fraction' of a mineral deposit, bore hole (bore hole interval), rock outcrop, or individual sample. Fabric elements may be related to any of these rock entities, and may have relationships defined with other fabric elements. Almost any entity in the model may have one or more free text 'observations' associated with it. The model relegates development of systems of terminology to individual implementations of the model. The model does not attempt to describe geologic maps.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia has also developed a model for Geoscientific Spatial Information systems (Lamb et al., 1996; Lamb et al., 1994; Power et al., 1995; <http://www.ned.dem.csiro.au/research/visualisation/DMGE/>). This is presented as an object-oriented data model that contains classes describing: geometry and topology of 3D geoscience entities, an audit trail for tracking sources of information, an information quality hierarchy, a spatiotemporal database record hierarchy, and a few geoscientific entities. This is a physical model for implementation in a C++ programming environment. CSIRO is a member of the GOCad consortium and their model apparently uses a framework similar to that used by GOCad for spatial and topological data.

The Geological Survey of Canada (GSC) has supported development of the FieldLog software system (<http://gis.nrcan.gc.ca/fieldlog/Fieldlog.html>) to aid geologist manage geologic field data. The data model underlying FieldLog is described in general terms in Brodaric (1997). This model has been used for a number of years by geologist for collection and compilation of field data, and appears to provide a flexible, robust, and expressive structure for collecting, archiving and analyzing the geologic data that support spatial data presented on geologic maps. The GSC has also published a cartographic database standard that is a physical model for geologic maps in an Arc/Info environment (<http://www.nrcan.gc.ca/ess/carto/english/reference/GSCCDBS.pdf>).

The Geologic Survey of Colombia (INGEOMINAS) has published some information on their model for geoscience data (Murillo, 1995). This data model was designed for INGEOMINAS as a means to integrate database operations over the domains of geology, geophysics, mining, geoenvironmental engineering, samples and wells. The fundamental entities in this data model are Observation Point (any location), the Spatial Reference Plane (spatial coordinate frame for Colombia), and the Mapping Terrain Unit (a closed surface object having characteristics different from surrounding units). No underlying conceptual model is elucidated in the description of this model.

Most participants at this conference are probably familiar with the standard data model proposed by the USGS, AASG and GSC (Johnson et al, 1998). Other efforts in the USGS have produced implicit or explicit data models. Implicit models underlie two significant software programs: AlaCarte, developed for geologic map data entry using Arc/Info (Fitzgibbon, 1991; Wentworth, 1991), and GSMCAD (Williams et al., 1996), developed for PC-based geologic mapping. Descriptions of the conceptual models underlying these packages are buried in the details of the physical implementations. Matti et al. (1997a, 1997b, 1997c) describe a unique physical data model using a linguistic root-suffix coding scheme. This model provides extensive hierarchical word lists that serves as an excellent guide for the concepts that need to be represented in a successful geologic knowledge base.

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Data Model for Single Geologic Maps: An Application of the National Geologic Map Data Model

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INTRODUCTION

After more than ten years of application of digital systems to the compilation, editing, and publication of moderate to large-scale geologic maps, USGS geologists on the Western Geologic Mapping Team routinely produce, and many of our customers expect delivery of, both digital spatial databases and paper map plots instead of traditional printed maps. Efficiencies in publication are also urging us towards release in digital form. We are beginning to encounter problems, however, because of differences in geology, applications, customer expectations, and the lack of agreement on standards for large-scale geologic map data. The very energy and creativity of the digital geologic mappers themselves have led to a proliferation of approaches to the preparation and delivery of modern geologic maps.

Within the Western Geologic Mapping Team, several funded projects have developed different approaches to digital geologic-map development. In our Las Vegas project, maps have been produced using a CAD program and then converted into Arc/Info format for release (for example, McKee and others, 1998). In the San Francisco Bay project, scientists ordinarily use ALACARTE (Fitzgibbon, 1991; Fitzgibbon, and Wentworth, 1991; Wentworth, and Fitzgibbon, 1991), a menu and standards system for Arc/Info developed ten years ago as one of the first successful systems for rendering geologic map information digital (used, for example, in Brabb and others, 1998). In southern California, the Southern California Areal Mapping Project has developed a more complex data model (Matti and others, 1997a,b,c) to produce numerous maps for publication and for fulfillment of various contracts (for example, Miller and others, 1998), while in the Pacific Northwest, geologic mappers hope for better weather and input their data in their own fashion.

If such variation exists within just one team, consider the diversity of approaches across the whole spectrum of producers and users of geologic maps. And yet the need for effective communication with customers and internal efficiency should be driving us towards common practice and standards. We have an urgent need to present a common face to the outside world and to be able to move data sets from one place or project to another. This paper describes my effort to move a group of creative and productive geologists towards agreement in the form of their digital products without interrupting the flow of work or denying needed flexibility in content and procedures.

GOING ENTIRELY DIGITAL

Two years ago, I began a campaign to expand digital work in the team to ensure that all newly released maps published by the Western Geologic Mapping Team were fully digital, including a graphics file (the cartographic map), a readme (first cousin to metadata), and a spatial database. Many team members were already working this way, but for some this required moving from digital graphics to GIS, and for others it required diving into the digital world for the first time.

In implementing this digital-only policy, it soon became clear that, as is often said, the devil is in the details. The serious practical issues surrounding database design, content of layers, needed attributes and the codes to describe them, the role of relates and lookup tables, and a myriad of other details presented themselves to the geologists immediately. Work simply couldn't proceed without practical means of addressing these seemingly mundane issues. At the same time, demanding users expected, by turns, traditional printed materials, preliminary plots, Postscript and PDF files, or full-blown ARC coverages to be downloaded in their own computers, all with rapid delivery. The various projects, with their resourceful scientists, seemed to find almost innumerable ways to solve these problems and deliver the required materials. This creative diversity came, however, at the price of consistency, compatibility, and efficiency.

Fundamental to a digital geologic map is the organization of its spatial data into topical layers and database tables, as well as the encoding of its other parts (table 1). It became clear that we all needed to agree on a standard model for encoding the spatial data before we could proceed to address the other details. Within the team we had the data model inherent in ALACARTE (the ALC data model), the new and rapidly evolving SCAMP data model, as well as other developing and ad hoc data models not yet formally documented.

It was also clear that, regardless of any future migration to other applications, we now needed to work within the practical constraints of Arc/Info: the Geologic Division requires that map datasets be released in Arc/Info as well as SDTS format (GD Policy 6.1.3.2), Arc/Info has become virtually the lingua franca of geologic mapmakers, and ARC export format is the single most useful exchange format for our customers.

At the national level, the draft National Geologic Map data model (Johnson and others, 1998a, b) provides a structure for a national data library that is designed to accept data from, and track the differences between, many disparate geologic maps. Accommodating these differences leads to complexity that is not needed for individual geologic maps, and the model cannot be implemented in Arc/Info. It does, however, provide us with a useful framework to help guide our development of team standards for the release of new, medium- to large-scale maps produced within the context of a team mapping project.

We call this partial implementation of the NGM data model the Single Geologic Map (SGM) data model. By single we mean that the model addresses the encoding of individual geologic maps. The SGM data model must be able to encode all the information represented on each map in such a way that the digital version of the map (including both the spatial and attribute data) can be released as a self-contained USGS publication. Adjacent maps with compatible stratigraphies, line categorizations, etc., can be mosaicked to create a regional data library or the maps can be uploaded into the national database.

GOALS AND CONSENSUS

The single geologic-map data model is being developed under three broadly defined objectives: (1) to continue to serve the needs of the map users, (2) to provide consistency and compatibility within the team, and (3) to be compatible with the single-map components available within the NGM data model.

The SGM data model must have certain properties. It needs to address the encoding of the information found within a standard paper geologic map (table 1), and it needs to define an agreed-upon model within which the data can be stored and exchanged. The data model must be backward compatible to the extent that all our previous creative and labor-intensive development work is not wasted. It must be as simple as possible and it must be able to be implemented in Arc/Info.

In developing this model, it has been important to follow a process that could develop consensus among the map producers of the team. The model has to build upon the current state of knowledge and application, thus taking advantage of our existing experience and capability and avoiding the need for complete retooling. It has to draw in the existing practitioners by providing them clearly recognizable advantages, and it has to be able to accommodate new requirements while retaining maximum flexibility (future expansions of the model shouldn't break earlier datasets). Finally, we have had to create a model that is not too great a departure from the products with which our users are already familiar and able to use.

THE SINGLE GEOLOGIC MAP (SGM) DATA MODEL

The SGM data model defines two fundamental geologic map layers: a units, contacts and faults (UCF or geology) layer, and a structural data (SD) layer. Other layers are permitted but not defined at this time. SGM uses the vector spatial data model, also known as the geo-relational or arc-node-topological model, in which points, lines and polygons (area boundaries) represent spatial features. Attributes are stored in relational database tables linked to the spatial features by common identification numbers. Standard vocabularies for attributes are not yet defined in the SGM model, but all attributes must be documented within the dataset's definition tables.

Table 1. Typical parts of a standard geologic map

Map graphic	Spatial data, drawn in a projection in XY space
Description of map units	DMU: map symbols and text descriptions of the units
Correlation of map units	CMU: graphic depiction of the age relations of map units
Text	
Cross section(s)	Spatial data, drawn along a vertical profile (in XYZ space)
Other illustrations	

Each of the two map layers consists of a spatial layer and its associated attribute tables (figure 1). Two types of spatial features are grouped in each layer: arcs (faults and contacts) and polygons (geologic units) in the UCF layer, and arcs (structural lines) and points (structural measurements) in the SD layer. This natural grouping facilitates queries and avoids the problems of duplicate storage. It can be implemented simply in Arc/Info and is routinely used in ArcView and other GIS packages. Each spatial layer also includes digital registration tics.

Associated with each of these feature types are three database tables containing attributes. The first is the feature attribute table, which contains one record for each spatial feature (such as a fault). This table contains identification numbers for each feature, topology fields (if any), area, perimeter and(or) length as appropriate, a unique primary key field (ITEMID), and a single characteristic descriptive attribute (see below). The feature attribute table for polygons is termed a Polygon Attribute Table (PAT), for arcs an Arc Attribute Table (AAT), and for points a Point Attribute Table (PAT).

The second table is a definition table, also known as a lookup table or domain table. This table contains expanded definitions for each unique attribute in the corresponding feature attribute table. Therefore the relationship is many-to-one, the "many" being the set of records in the feature attribute table that share a common attribute (e.g. all polygons with ULABEL of Kgr), and the "one" being the single record in the definition table that describes that attribute (e.g., Cretaceous granite of Hidden Wells). Each definition table can contain additional items, including cartographic symbol assignments.

The third table is an ID Table, which can contain additional attributes, such as strike and dip for a structural measurement, for each individual spatial feature. The relationship is one-to-one with the corresponding feature attribute table. These attributes are placed in the ID Table rather than in the feature attribute table to keep that table as small as possible. This enhances the speed of many GIS operations, and makes the equivalent feature attribute tables of every map database identical in structure, which permits easy mosaicking. Any additional attributes are placed in the ID Table, whose structure can vary between adjacent maps as required.

The units, contacts and faults (UCF or geology) layer is required for all geologic maps, and contains arcs and polygons. Polygon and arc topology must be present. Arcs represent contacts and faults (as well as water boundaries and the map boundary); arcs that are not part of a polygon boundary (dangling arcs, e.g. some faults) are permitted. Arcs with polarity (e.g. low-angle faults) must be encoded with right-hand rule. The characteristic attribute in the UCF.AAT is LTYPE (for line-type, e.g. thrust fault or contact); the definition table, UCF.LN, adds

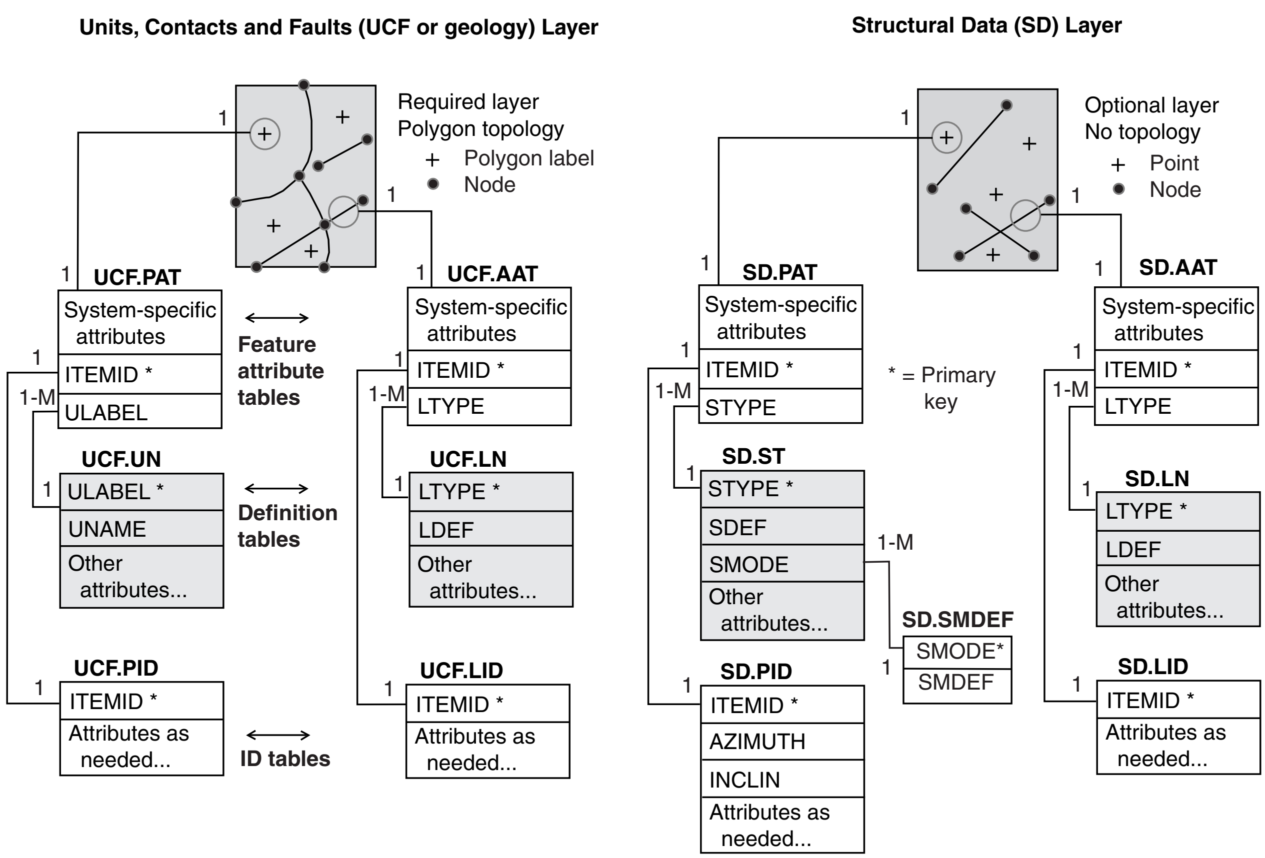

Figure 1. Single Geologic Map (SGM) Data Model.

the LDEF, the line-type definition. Polygons represent geologic units and consist of bounding arcs and a single label point internal to each closed polygon. The characteristic attribute in the UCF.PAT is ULABEL (for unit-label, e.g. Kgr, Qal). The definition table, UCF.UN adds UNAME, the formal or informal name of the map unit.

The structural data layer (SD) is optional and contains points and lines; no topology is present (no intersections where structural lines cross). Points represent structural measurements such as attitudes. The characteristic attribute in the SD.PAT is STYPE (for structure type, e.g. bedding or lineation). The definition table SD.ST adds SDEF, the full definition of each STYPE, and SMODE, the convention used to record orientations (e.g. strike and dip, trend and plunge). A separate table, the SD.SMDEF (for structure mode definition), defines each of these modes or conventions. The point ID Table (SD.PID) contains the structural measurements, AZIMUTH and INCLIN (inclination), for each point. Arcs in the structural data layer represent structural lines such as fold axes. The characteristic attribute in the SD.AAT is LTYPE (e.g. anticline). The SD.LN definition table adds LDEF, the definition of each unique LTYPE.

The relationship of the SGM data model to the National Geologic Map data model is straightforward. The spatial layers and their associated feature attribute tables correspond to the Spatial Object Archive in the NGM data model. The SGM Definition Table is a simplified subset of the tables in the NGM Compound Object Archive. The SGM ID Tables correspond to the tables in the NGM Singular Object Archive, with the difference that the SGM data model currently allows a single record in the ID Table for each spatial feature. In a later SGM version, we expect to provide for multiple records referring to single map elements in order to accommodate coincident features such as multiple observations at a locality.

CONCLUSIONS

The SGM data model has been developed specifically to address the practical problems encountered on a daily basis as we work to develop and deliver digital geologic maps. It is designed to serve our immediate needs for a common storage and exchange format and to be expanded as we develop consensus on how best to encode other parts of a geologic map. We expect this expansion to move the data model progressively toward the full NGM data model. The SGM model must be immediately practical, and as a first step in implementation we have prepared AML tools for use in Arc/Info to convert between the ALC and SGM models and to operate on the SGM definition tables in ALACARTE. Further tools, converters, and continuing support for the SGM data model will be developed and provided by the team as needed, with the ultimate goal of having tools with which to compile, edit, query, and publish directly in the SGM model.

We view the SGM model as a means to present a standard face to each other and our users, but also as a mechanism by which to draw our GIS practitioners together and to stimulate the joint development of tools and procedures of common value. We invite participation by others in this development process and welcome active participation in devising, testing, and adopting expansions to the model and to the tools and procedures with which to use it. The descriptions, code, proposed expansions, and discussions are available at our GIS web site http://geology.wr.usgs.gov/techniques.

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Using the Proposed U.S. National Digital Geologic Map Data Model as the Basis for a Web-Based Geoscience Library Prototype

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ABSTRACT

We have developed an internet-based digital library prototype (CordLink) to seamlessly integrate digital maps, images and text on Canadian Cordilleran geology into a comprehensive information resource for the geoscientist and non-geoscientist. The library structure addresses several factors that make geological knowledge challenging to use in an internet environment: (1) geological data is multidisciplinary and diverse (e.g. bedrock mapping, geophysics, geochronology, mineral resources, etc.); (2) it is expressed in multiple forms such as map, text, and image; (3) it is extremely inter-related with no piece of knowledge captured in any one fragment or form; (4) it spans geographic space and geologic time; (5) it is expanding and evolving; and (6) users tend to peruse library holdings within a specific geographic, geologic, or level of expertise context. These factors require an approach to data management that, while it is distributed in nature, is more structured and context-sensitive than the simple linking of a myriad of web pages.

The CordLink holdings are held in a relational database system arranged according to an extended version of the proposed US National Digital Geologic Map Data Model design (<http://ncgmp.usgs.gov/ngmdbproject>). The database is coupled to the Internet-based Autodesk MapGuide Geographic Information System (GIS). Users can enter the holdings from the Map, Document, Image, Education or Research perspectives and can then navigate the library according to subject while preserving their initial focus. Derivative thematic maps and reports can be constructed and generated by the user on-the-fly for superior browsing capability. Various library holdings can be downloaded and users can contribute elements to the library. A catalog of on-going research projects is provided as well as an on-line scientific discussion forum. It is anticipated that this wide-ranging, tightly inter-linked resource, delivered in a visual environment, will benefit researchers, students, instructors and the general public.

INTRODUCTION

The Internet possesses enormous potential to enhance the distribution of geological information, and to broaden the scope of its usage. The convenience of the Internet ensures that geological information will be accessed more often and more diversely than ever before, and it will no doubt attract more non-traditional visitors to geological information than, for example, did the libraries or sales offices of geological surveys. In this, however, it could serve to alienate as many people as it attracts, for, like many professions, geology is a field that is difficult to comprehend by the uninitiated. This is disturbing in light of the attention that geological agencies are now directing to outreach and societal benefit. Note, for instance, that the strategic directions of both the Canadian (GSC) and US (USGS) geological surveys emphasize this societal theme:

"Its (GSC's) goals are threefold:

- to create centres of excellence in Canada for scientific research and the advancement and dissemination of knowledge,
- to better apply our scientific knowledge in achieving Canada's economic and social goals, and
- to contribute to a better quality of life for Canadians." (GSC, 1996).

> "The challenge for the USGS is to stay focused on a horizon of some ten years out, while realizing that there will be near-term shifts… Beyond these already compelling factors are the public's perception of its investment in science as a means of solving societal problems and society's concept of the "public good" of science." (USGS, 1997).

Therefore, the challenge of the Internet extends beyond making geological information available, for that is readily done; it must instead make this knowledge more useful to geologists and more relevant to other parts of society.

It seems clear, at least to many geologists, that fundamental geological investigation can play an important role in understanding and managing the relationship between humans and the natural environment. This role, however, is not readily evident in traditional geological products such as maps or databases, but must be teased out of them by geological experts. This effectively undermines the broader use of the information and diminishes its value to the non-geologist. Combining modern GIS tools with the Internet yields technology capable of overcoming this situation; however, how to structure, present and manipulate geological knowledge, in its fullest sense, to other parts of society, is not clear.

What does seem clear is this: if the Internet is to serve as the gateway to the public, it is incumbent on geological data providers to ensure that geological knowledge is represented to its fullest degree, and that it is accessible and usable by professional geologists and casual visitors. This requires two major interacting components, one representational and the other functional: firstly, a data model for geological knowledge is required to meaningfully structure geological information, and secondly, a suite of operations tuned to both geologists and non-geologists is necessary to leverage such a structure. The remainder of this paper describes these two elements. The requirements for a comprehensive geologic site are discussed first, followed by the data representation methods required to make it work. Finally, an Internet site that endeavors to meet these criteria, by serving the geology of Canadian Cordillera, is described.

REQUIREMENTS

Data, Information and Knowledge

What we know is often categorized as data, information and knowledge. In a geological sense we can see this as an increasing gradient in our understanding of the interaction of earth processes and materials: data are measurements, facts and observations; information is data in context, such as the interpretations on a geologic map; and knowledge represents the complete understanding that we possess in our minds of some thing, such as a geological history of an area. Thus the computer representation of real *knowledge* is very difficult, and arguably impossible, as we can't capture human thought (at least not yet). The most we can do is mimic human thought via knowledge representation strategies and reasoning mechanisms that create the impression of real thinking—some would argue that this indeed constitutes machine intelligence, if we can't distinguish between machine and human behavior (Turing, 1950). In terms of geological computing, this implies two things: firstly, that we must maximize our knowledge representation efforts, and secondly, that we must provide superior functionality so that the geological content that is represented is used intelligibly and will appear to be, in fact, knowledge.

Knowledge Representation

Knowledge representation for computing purposes requires the objects and their relations in the real world to be translated into objects and relations in the computing world (Luger and Stubblefield, 1998, p. 293). In effect this states that knowledge can be approximated in a computer by carefully cataloging and indexing information (and then using it). We must therefore carefully identify the geologic objects to be represented and maximize the relationships between them. This is analogous to placing the information in as many contexts as possible, and is particularly relevant to geological mapping where information can be viewed quite differently according to a geologist's expertise, education or bias. In non-digital environments the expression of a viewpoint is usually a multimedia affair, often requiring maps, reports, charts, diagrams and oral presentations to convey a message. How can computing mechanisms cope with such diversity?

At a gross level, for computer representation purposes, we can also attempt to categorize the objects of geological knowledge to be maps, documents, images, projects, and references. Though it is worthwhile to view a map alongside its accompanying reports, diagrams, bibliography, and general project description, it is much more useful to actually interconnect the sub-components of these elements to permit investigation at a more detailed scale. For instance, selecting a polygon on a map and viewing its unit description, embedded in reports or articles, as well as displaying related images such as age correlation charts or cross-sections, or obtaining references specific to that map unit, would be much more beneficial. Narrowing our scale of focus to field observations would be of even greater benefit, though the task would be much more difficult as the relationships between field observations and their interpretations is multitudinous and complex. This suggests the basic resolution for the represented objects could be quite fine, and their relationships abundant and intricate. Designers of geological software must select an appropriate scale of representation based on their purposes, and on the quantity and quality of the information content. A medium scale of object resolution could include:

- ***Map***: legend, map unit, occurrence.
- ***Geological Description***: lithostratigraphic age, geochronologic age, lithology, and others.
- ***Document***: volume, chapter, subsection, figure.
- ***Image***: caption and image.
- ***Project***: originating project details.
- ***Reference***: citation and source details.

The ideal system would permit relationships between any of these elements to be represented. For instance, one might relate a lithostratigraphic or geochronologic age to a body of text, to a figure, to a map unit or to a map. Likewise a map unit might be associated with one or more geological descriptions, document segments, figures, projects or references. The ability of establishing such relationships elevates the context of any single information fragment and thus increases its knowledge content. Furthermore, this design is scaleable as geological descriptions could be expanded to contain the more complex field observations.

Knowledge Usage

A fitting model for how geologic objects are to be used, rather than what they are, is the library: libraries are valued for their archival role as well as for their ability to stimulate new thought. Library contents possess the potential to foster new insight and thus to regenerate themselves with new contributions. This implies that information requires discourse to achieve the rank of knowledge. Applying this to digital environments suggests digital libraries must not only represent original author intention but must promote scientific discourse by enabling the representation of different viewpoints. They should be inclusive of diversely formatted and conceived documents, and also encourage various methods of discussion. Today these ideas are perhaps best exemplified by the Internet, its interconnection of computers known as the world wide web, and its loose arrangement of information fragments. Many researchers suggest that this arrangement is not optimal (e.g. Schatz, 1995), and contend that the web requires mechanisms to add context to its information fragments, which essentially means increasing the resolution of its objects and relations. Why is this so ?

Implementation

The world wide web is a form of knowledge management system at the document level. It primarily maintains links between documents (consisting of images and text), and permits searching for text strings within the documents. A first order approach to placing geological information on the web would be reduce the geological information to a set of text and image documents that are interlinked, and simply use the web's navigation capabilities to traverse them. There are several problems with this approach:

1. Spatial representation: Maps are treated as diagrams rather than spatial constructs. Smart graphic formats (e.g. CGM) will allow individual elements to retain linkages to other document components, but how adjoining maps fit together, for instance, is beyond the basic web.
2. Spatial operation: searching for information inside a map unit or close to a fault is impossible.
3. Contextual searching is impossible: searching for the inclusion or exclusion of words within a document is the limit; applying contextual parameters is impossible: e.g. searching for map units of a certain age will return any geological or non-geological document that contains the specified text.
4. There is no provision for the management of information. For instance, no referential integrity is implemented—this means, for example, that the spelling of terminology could not be standardized, which causes searches to return incomplete results.

Thus, we can view the web as a very valuable document server, but not as an analytic tool. Missing is the geological context that is crucial to its effective use. Industry and academia are spending significant resources to address these problems, through various digital library initiatives (see National Coordination Office for Computing, Information and Communications, 1998). Although considerable progress has been made, the contextual web is not yet a reality today. This suggests that practical applications must, in the short term, implement traditional technologies to manage the objects and relations of interest to us, and this implies that database systems and GIS must be harnessed to the Internet to serve as our knowledge engines. Of the two technologies, only the database system permits conceptual extensions, as GIS are fixed in one spatial model or another. For example, vector-based GIS typically offer points, lines and polygons, and the topological relations between, as their spatial primitives. The user-defined meaning of these spatial objects and their relations is typically contained within a database.

From this it is apparent that it is increasingly important to develop and adopt a database design that contains relevant geological objects and encourages effective usage of them. The medium scale objects noted above (maps, descriptions, documents, images, projects and references) provide a good starting point for a database design that is knowledge-oriented. How well do our current data modeling efforts meet these criteria?

GEOLOGICAL MAP DATA MODEL

The geological map has evolved into a highly concise articulation of the geological history of a specific geographic region. Though its graphic nature makes it eminently suitable for web-based knowledge delivery, its complexity and diversity challenge simplistic conceptions of what a digital geologic map is, and how it functions. The U.S. National Digital Geologic Map Data Model effort addresses the first of these issues, by defining the components of a geologic map. The prototype data model 4.3 (<http://ncgmp.usgs.gov/ngmdbproject/>) is designed to represent the most common elements of geologic map data, and is thus well suited to representing Map, Geological Description and Reference objects and certain relations amongst them:

1. Reference sources, including maps, as well as legends, legend items (e.g. rock units) and their relations, are defined thematically and cartographically. This permits geological map information to be organized coherently, in databases, while preserving their map origins.

2. Geological descriptions consisting of lithologies and ages (geochronological and lithostratigraphic) are associated with legend items or individual map occurrences (e.g. with one rock unit polygon, or one thrust fault line).

3. Geologic vocabularies for rock types, time scales and structural features can be defined, extended and standardized. The use of hierarchies enables the development of terminological standards that require consensus at higher levels but that may be modified according to user need at lower levels.

4. Geologic information is separated from spatial representation, permitting a geological feature to have different spatial representations (point, line, polygon, volume, etc.) by existing on different maps, at various scales, or because of diverse interpretations.

However, in keeping with the stated intention of storing knowledge by maximizing geological context through enhanced representation (objects and relations) and function (digital library operations), several aspects of this design require modification:

1. Objects of representation—missing are document, image, project and dataset objects:

   A. *Document*: a repository for bodies of text comprising reports, journal articles, theses, etc.

   B. *Image*: a repository of images including georeferenced remote-sensed maps (e.g. geophysics), as well as diagrams from a map's surround, or figures from a body of text.

   C. *Project*: a record of recent, current and future geological activities, their purposes, goals and locations.

   D. *Dataset*: a description of the physical layers comprising a map including supplemental information about a dataset such as its name, location, layer type (e.g. line, point, polygon).

2. Relations between objects:

   A. *Description independence:* this requires establishing a description archive where geological descriptions, such age ranges, rock compositions, and other description types (e.g., images, text, projects, mines, wells, boreholes, etc), exist as independent entities that may optionally be related to one or more rock units or to other descriptions. In v4.3 this is not the case, as age ranges and rock compositions must be related only to a specific rock unit.

   B. *Description relations:* denotes the complex relationships between geological descriptions. It would, in effect, permit any description to be related to any other description. This is of specific importance to medium scale geologic knowledge representation as it permits, for example, text fragments to be associated with ages, images, projects, field sites, measurements, etc., thereby cross-indexing the geological content according to different perspectives.

   C. *Subject indexing:* a generic, hierarchical, subject listing that can be used to index digital library holdings and thus provide novice as well as expert search capability.

Modifications 2a and 2b have been discussed within the former U.S. national geologic map data model working group (<http://ncgmp.usgs.gov/ngmdbproject/>) and have been adopted by the CordLink library. The remaining modifications result from implementing a digital library approach to geologic information within the Canadian Cordillera (Brodaric and others, 1999).

A DIGITAL LIBRARY IMPLEMENTATION FOR THE CANADIAN CORDILLERA

A large database of geologic maps for the Canadian Cordillera was constructed according to a data model design (Figure 1) modified from the proposed U.S. national v4.3 prototype. The database represents a digital library that contains five main geologic map series ranging in scale from 1:2,000,000 to 1:32,000,000 and covering a large geographic area including all of British Columbia, the Yukon, and parts of Alberta. These maps contain in excess of 210,000 individual map features, as well as about 3500 legend items, mostly rock units. Each rock unit is described according to absolute age range (e.g. 300-400 million years), geologic age range (Devonian-Siliurian), rock type composition (shale, siltstone, etc.), and is also linked to a cartographic symbol within a legend. The Cordilleran volume from the definitive Decade of Geology of North America (DNAG) (Gabrielse and Yorath, 1992) was converted to digital format and compartmentalized, including more than 800 pages of text and 500 images. Text components were indexed according to their geologic age and subject, and to relevant figures and images, and to related rock. Users are thus able to retrieve authoritative descriptions, including text and images, when viewing any feature instance on a map; users are also able to enter the archive from the text and image perspectives, with all interrelationships maintained. The description and location of research projects can be viewed on-line, and users can enter their own research project information. A discussion room is being provided to encourage discourse on geoscience topics of current interest. Some map data may be downloaded and an education component maintains links to education sites within the geosciences.

The library is constructed to operate in an Internet environment, by utilizing the Autodesk MapGuide software (<http://www.mapguide.com>) to display and contain its spatial aspects; the remaining non-spatial aspects of the database are hosted within the MS SQL Server relational database environment. These two components were integrated into an attractive and functional user interface through extensive JAVA programming, performed by an external contractor.

The library can be viewed using MS Internet Explorer v4.0 or Netscape 4.5 once the appropriate plug-in is installed. Although the web site's definitive address is still unknown, the CordLink digital library is accessible via <http://www.rgsc.nrcan.gc.ca> (follow the CordLink link). It is anticipated the site will enhance geological research and geological education through the digital interconnection of the various map, text and image components.

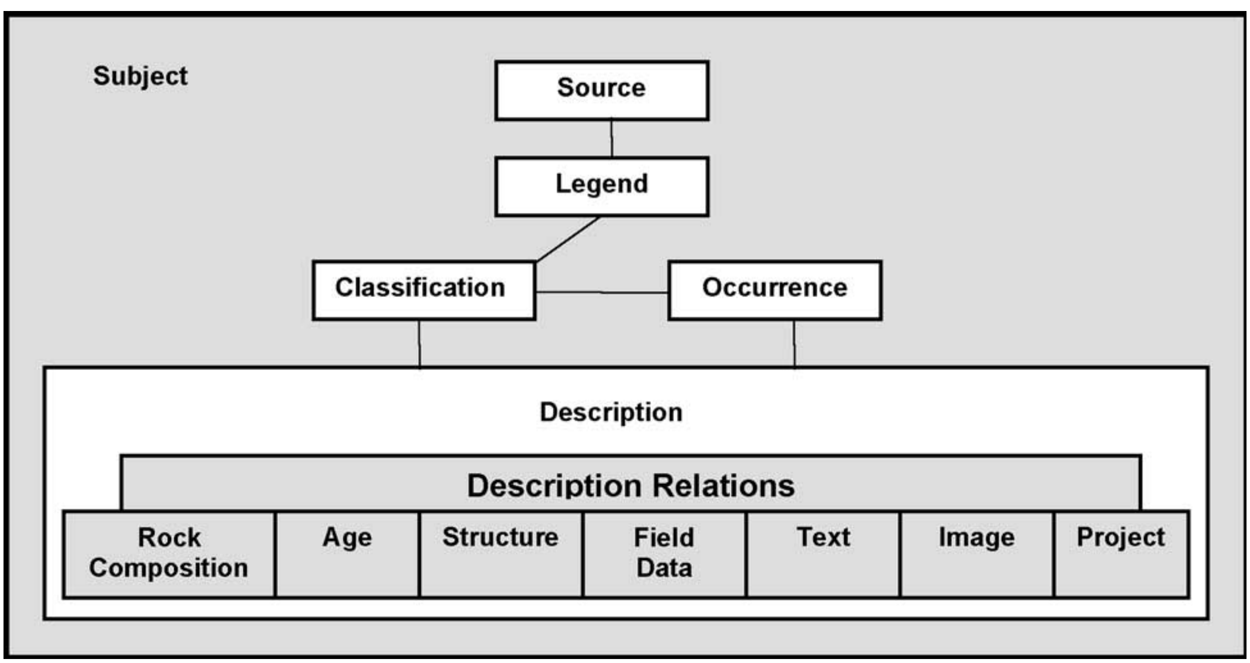

Figure 1. A diagram depicting the enhanced digital geologic data model utilized by the CordLink project

The web site is arranged according to 8 main modules: *Maps*, *Documents*, *Images*, *Research*, *References*, *Data Download*, *Education*, *Search*.

Home

The Home page (Figure 2) provides an entry point to the main modules, as well as an overview of the site including information about its intent, content, system requirements, its development team and other partners.

Maps

The Maps module allows maps and ancillary data to be viewed and queried at various scales. The geologic map and ancillary data available is tailored to the viewing scale: regional views will depict general maps and data, and as the user zooms into a detailed area more relevant, detailed information is provided. Users are able to peruse the holdings according to a subject index or geospatially, through a scale-sensitive legend. Table 1 provides a partial, representative, listing of the available maps and datasets.

The *Maps* module also enables map features to be thematically filtered and inspected according to their legend description (e.g. rock unit, age or lithology) and related document fragments and images. For example figure 3a depicts a portion of the 1:2,000,000 tectonic assemblage map of the Canadian Cordillera (Journeay and Williams, 1995) where a set of map features containing Basalt, at least in part, were identified (outlined with dashed lines). Figure 3b illustrates how a specific polygon in this set is described in terms of rock unit (i.e. Cache Creek), DNAG (Gabrielse and Yorath, 1992) text and image.

Documents, Images and Research

The *Documents*, *Images* and *Research* modules are analogous to the Maps module: their contents are indexed according to subject, and provision is made for selecting and viewing module contents according to related map, image, text or project information. Of course, the primary viewing window is focused on the module's media type: a map is displayed in the *Maps* module, text is displayed in the *Documents* module, an image is displayed in the *Images* module, and a project location map is displayed in the *Research* module. Smaller windows then present the remaining media type information. The *Images and Research* modules additionally permit users to insert their own contributions to the library via an on-line interface, whose content is reviewed by a digital librarian. Currently, image contributions must be transferred to the Cordlink site, though it is expected they could remain remotely located in the future. The research module also maintains an on-line discussion platform that encourages scientific discourse.

References, Data Download, Education, and Search

The References, Data Download, Education and Search modules provide several important functions:

Figure 2. The Home page for CordLink—a digital library prototype for the Canadian Cordillera.

Table 1. A partial, representative, listing of geoscience data found in the CordLink digital library.

Author	Date	Title
H.Gabrielse and C.J. Yorath	12/31/91	The Geology of the Cordilleran Orogen in Canada
Wheeler J.O., Hoffman, Card, K., Davidson, T., Sanford, Okulitch, and Roest	3/31/97	Geological Map of Canada - 5M
Kirkham, R.V., Chorlton L.B. and Carriere J.J.	1/30/95	Generalized Geology of the World – 32M
Fulton, R.J.	1/30/97	Surficial Materials of Canada - 5M
Journeay J.M.and Williams S.P.	3/30/95	GIS Map Library: A Window on Cordilleran Geology – Tectonic Assemblages 2M
Journeay J.M. and Williams S.P.	3/30/95	GIS Map Library: A Window on Cordilleran Geology – Terranes 2M
Journeay J.M. and Monger, J.W.H.	3/30/98	Coast Belt Geoscience Library – 250K
B.C. Geological Survey		Map holdings, Mineral Inventory, Assessment Reports
B.C. Ministry of Environment	12/31/94	TRIM topographic base data
Various	12/31/94	topographic data
Various	4/1/99	Shaded Relief – DEM
Various	4/1/99	Satellite Image
Various	4/1/99	Bouger Gravity
Various	4/1/99	Aeromagnetic
Various	4/1/99	Earthquake epicentres
C.J. Hickson and B. Edwards		Volcanoes
G.J. Woodsworth		Geothermal resources

- References: provides access to references within the CordLink site, and links to other Canadian geoscience reference libraries.
- Data Download: currently permits a select subset of the available maps to be copied by the user to their local computer, in a variety of common geospatial formats.
- Education: provides access to on-line education resources related to Canadian goescience.
- Search: a generic mechanism to locate document level information (i.e. metadata) within the library. Document level information refers to title, author, subject, etc., descriptions of maps, reports, images and other documents; it does not refer to their internal contents.

FUTURE DIRECTIONS

The CordLink project is one component of the ResSources GSC digital geoscience initiative within the Geological Survey of Canada (<http://www.rgsc.nrcan.gc.ca>). The goal of this initiative is to link significant GSC data holdings across the Internet, in order to facilitate their dissemination, integration and general interoperability. The ReSSources GSC initiative is itself part of a larger Canadian geoscience program, the Canadian Geoscience Knowledge Network (CGKN), which has similar goals and includes all the major Canadian federal, provincial and other geoscience data providers. CGKN is in turn a part of the Canadian Geospatial Data Infrastructure (CGDI), a national effort to make all geospatial data accessible and useable on the Internet. As CordLink is contributing significant regional Cordilleran geology holdings to these efforts, it is expected that the site will continue to evolve. In particular, it is expected that its current prototype status will be upgraded to a fully operational site in the next year. Longer term concerns include:

- expanding the distributed nature of the library, and
- enhancing its interoperability with other libraries,

without sacrificing the gains made in representing and using greater geological context. Advances in digital library research will resolve some of these issues and the CordLink library should be well positioned to adapt the solutions to its holdings and infrastructure.

CONCLUSIONS

A digital library approach to representing and delivering geological knowledge was implemented for Canadian

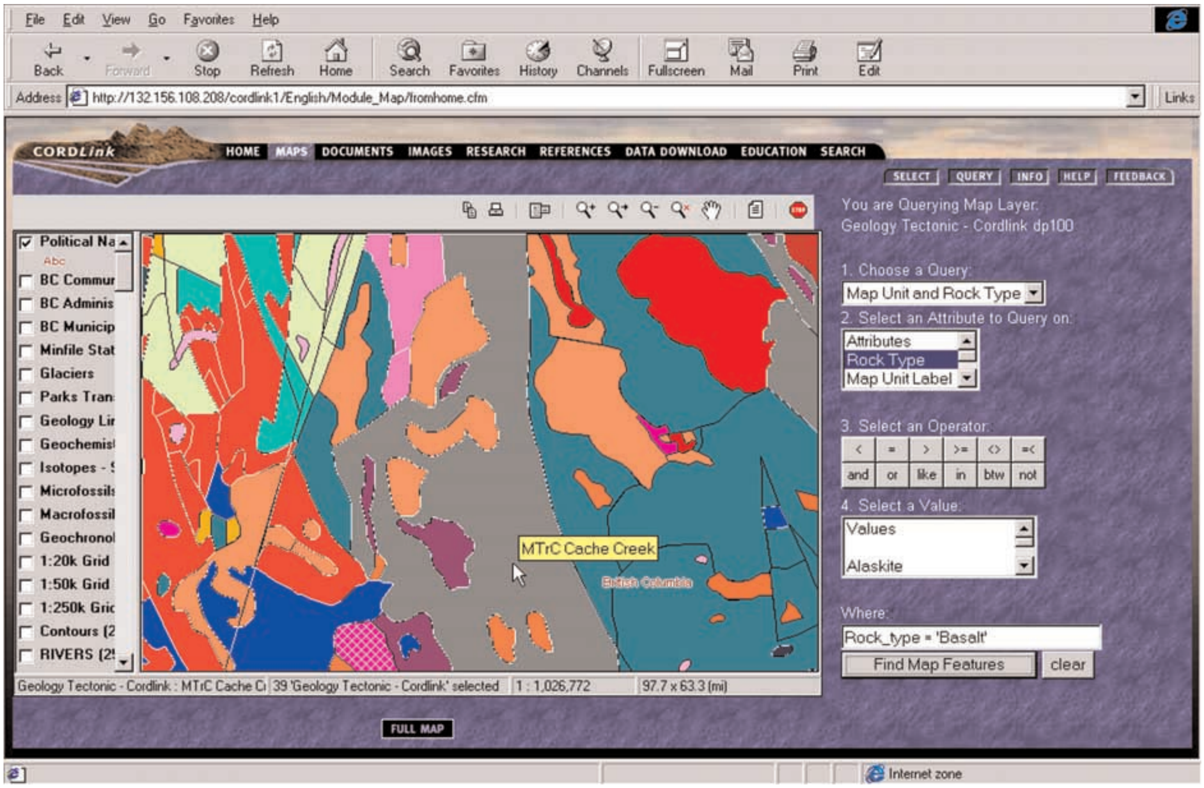

Figure 3a. The Map module displaying 1:2M tectonic units comprised, at least in part, of Basalt; the pointer has selected one specific polygon for further interrogation.

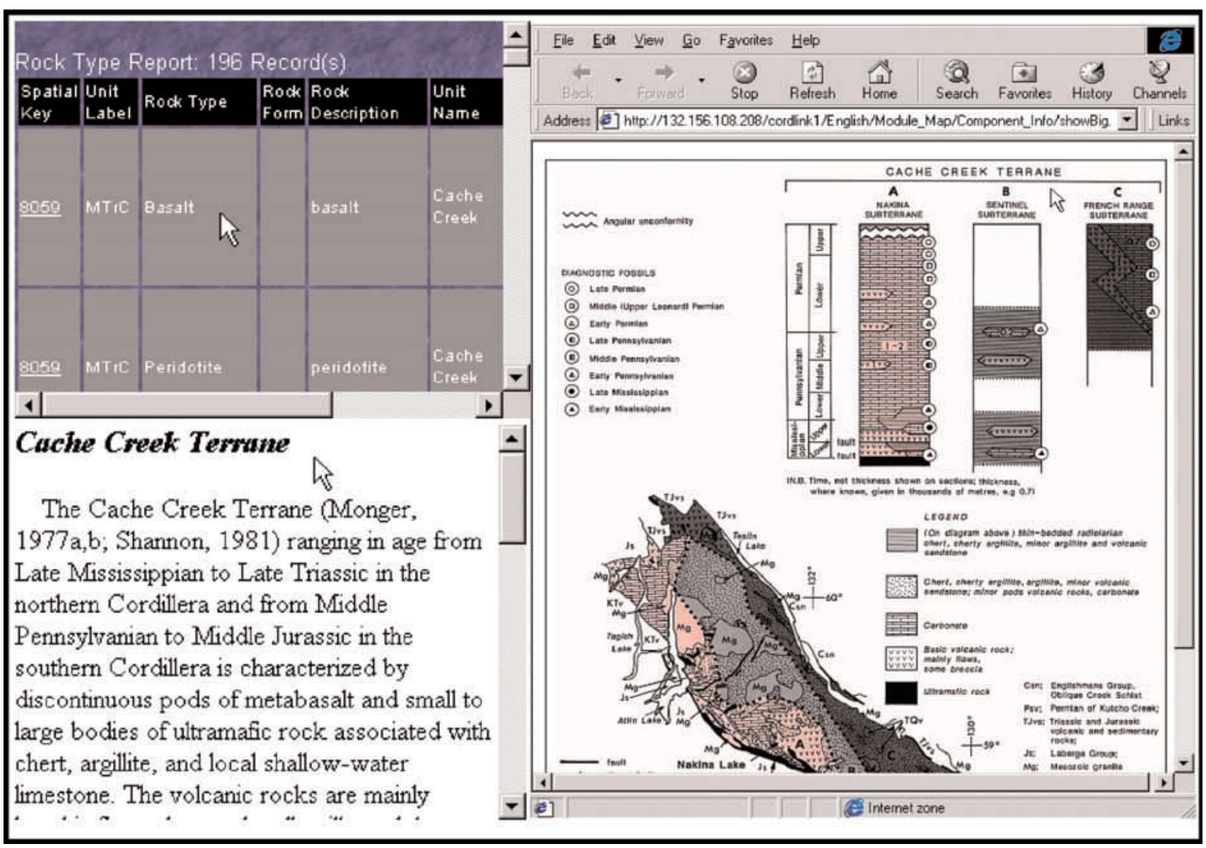

Figure 3b. The library contents of the polygon selected in Figure 3a are displayed as database table, DNAG text and figure.

Cordilleran geology. The digital library utilized the proposed U.S. national geological data model to augment the geological context of the data holdings in terms of database representation and end-user functionality. The proposed U.S. national digital geologic map data model was expanded to accommodate more geological data types and richer relations between the new, and previously defined, data model components. A prototype Internet-based interface was developed to exploit the geological data types and their rich relations. The results have been very satisfactory, in terms of proof of concept, and in terms of prototype implementation, and we anticipate developing the site further. It is hoped the digital library approach will promote the use of geological information, and knowledge, by using technology to enhance scientific investigation and thus to better meet the broader societal demands facing us today.

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The Geometry of a Geologic Map Database

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INTRODUCTION

One objective of the Geologic Mapping Act (GMA) of 1992 (re-authorized in 1997) calls for the establishment of standards for digital geologic mapping both for paper plotting and for a computer-readable database. One response of the U.S. Geological Survey (USGS) and the National Cooperative Geologic Mapping Program (NCGMP) to Office of Management and Budget Circular A16, Executive Order 12096 and the GMA, will be to establish a national digital geologic map database for use at a scale of 1:100,000. This work is to be conducted under the National Geologic Map Database Project (NGMDB) of the NCGMP.

In August 1996, in St. Louis, Missouri, the Digital Geologic Mapping Committee of the Association of American State Geologists (AASG) and NGMDB of the USGS, formed several working groups to devise standards and guidelines for various concepts that make up a geologic map in digital form. Information about these working groups is available at the NGMDB project web site, <http://ncgmp.usgs.gov/ngmdbproject>. One element of the geologic map database standards effort that has had little attention is map geometry.

The NGMDB needs to test the concept of a national geologic map database at a scale of 1:100,000. The Greater Yellowstone Area (GYA) is a region in which such a geologic database, built as a proof of concept, would add much to the understanding of the GYA ecosystem. The GYA encompasses an area five degrees in longitude (108 West to 113 West) and four degrees in latitude (42 North to 46 North). Forty 30' by 60' 1:100,000-scale quadrangle maps cover the GYA (figure 1). I anticipate that this pilot database will be used to supply geologic data for the GYA Science Initiative, a new part of the Integrated Natural Resources Science program (INATURES) of the USGS, which has become a part of the Department of Interior's Place-Based Science Program.

The NGMDB has the opportunity to test the results of its standards efforts on a database that is needed in the region by various interest groups, and that when integrated with other geospatial data sets of the GYA will prove to be vital for ecosystem management there. However, to insure the continued usefulness of the database, the geologic data in the database must be updatable and the GIS system must be able to keep careful track of the revisions as they are made. In addition, digital map databases from the state geological surveys of Idaho, Montana, and Wyoming will be integrated into the database. Each state survey will most likely have different ways of representing the geometry of their products.

To support the GYA database effort, I am converting unpublished "legacy" geologic map materials of W.G. Pierce for the geologic map of the Cody, Wyoming 2-degree sheet that lies on the east side of Yellowstone National Park in the northeast corner of the GYA (figure 1). These materials were originally compiled at a scale of 1:125,000. The density of line work and the level of geologic detail allow the capture of the data at a scale of 1:100,000. In particular, I am working with the unpublished Cody, Wyoming 1:100,000-scale quadrangle, which is in the northwestern quadrant of the Cody 2-degree map.

The Cody, WY 1:100,000-scale geologic map data exists as a film positive that was compiled by W.G. Pierce (1997) for the geologic map of the Cody 2-degree quadrangle (figure 2). Time constraints preclude the use of the seven published 15' geologic quadrangle maps as the primary source materials for the 1:100,000-scale map. The three other 1:100,000-scale pieces of the Cody 2-degree sheet are also unpublished and exist only as film positives. Large-scale source materials for these maps have yet to be located.

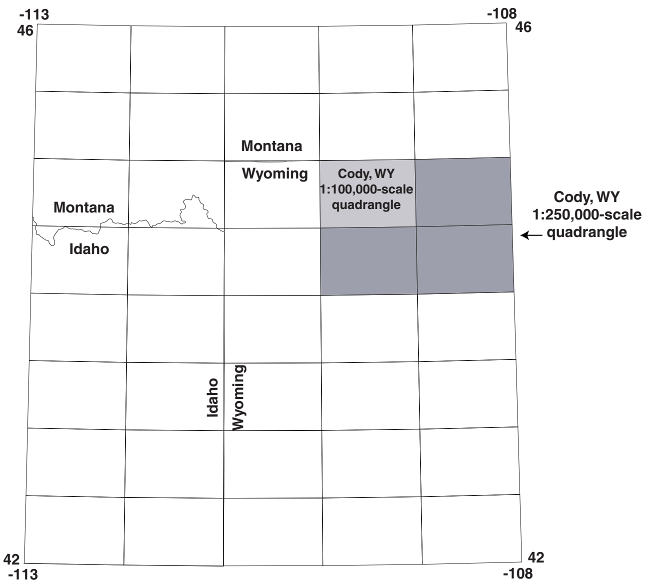


Figure 1. The Greater Yellowstone Area.

GEOMETRY AND THE DIGITAL GEOLOGIC MAP

Problems concerning the capture of the geometry of a geologic map database have arisen as I continue to compile the Cody 1:100,000-scale geologic map. The problems fall into three general categories. They are:

1. Capture of the "art" and at times subtle geologic concepts that the original compiler wished to portray.
2. Map-capture resolution and positional accuracy, and the relationship to National Map Accuracy Standards (USBB, 1947) and National Map Revision Standards (USGS-NMD, 1998).
3. Structure of the digital geologic map data and the specifics of a data exchange or transfer format to allow users (within and outside the GYA) with a number of different viewers and GIS tools to utilize the data easily.

It is clear, that although geospatial data can be transferred using standard transfer formats, the representation of geospatial objects such as polygons and lines contained in a digital geologic map database is not standardized.

CURRENT STATUS OF ACCURACY STANDARDS

As of this writing no report has been released by anyone including the AASG/USGS standards groups mentioned above, proposing any standards for map geometry including standards for geologic map accuracy, or map resolution. General policies for digital geologic map products have been issued inside the USGS, but outside the USGS only proposed guidelines exist for groups producing digital geologic map data (see Soller, Duncan, Ellis, Giglierano, and Hess, this volume). These guidelines do not mention map geometry. The OpenGIS consortium (OpenGIS, 1999), in their abstract series of documents, has published a framework about which map geometry and accuracy standards for the digital representation of geologic maps may be formed. In addition, the National Mapping Division (NMD) of the USGS published a document which details standards for updating already published 1:24,000-scale topographic maps (USGS-NMD, 1998; Lemen, this volume). For now, the National Map Accuracy Standard (USBB, 1947) and the update document might be used to determine the accuracy with which geologic objects can be placed on a map until a more appropriate standard is developed.

Problem 1: The capture of the geologic map "art" and concepts

Since the aforementioned 1996 meeting, I have expressed a concern that the "art" of a geologic map should be preserved as much as possible when the map is converted to a GIS database. The following example shows one of the connections between geologic "art" and concepts. Some 1:62,500-scale published geologic data near Pat O'Hara Mountain in the southeastern part of the Cody, WY 1:100,000-scale quadrangle, shows a number of older rocks units concealed by surficial materials. When these data were compiled on the 1:100,000-scale map, some but not all of these surficial deposits were omitted (figure 3). I think that Pierce eliminated these surficial units because he wanted to show the relationships among the older rocks and associated structures clearly. Maybe a future compiler of the Cody 1:100,000-scale map might want to show these surficial units. In doing so, however, the compiler would again have to answer the question: "What are the important geologic concepts that I am trying to portray and how might this best be done?". My objective in converting Pierce's original map to a digital form is to faithfully reproduce what Pierce recorded on his original map.

In studying the data from this locale on the Cody quadrangle, I conclude that there are no standard ways to represent linear data with characteristics more subtle than the primary attributes of "contact" or "fault". An implicit assumption is made for rock units older (or different) from Quaternary alluvium, that lines attributed as contacts show the top of one formation and the bottom of another. This information is indirectly found in age attributes in the data model. But what happens if the ages that are given for two formations are both "lower Cretaceous" and they are in contact in one place but not in another on the same

Figure 2. The Cody, Wyoming 1:100,000-scale geologic map.

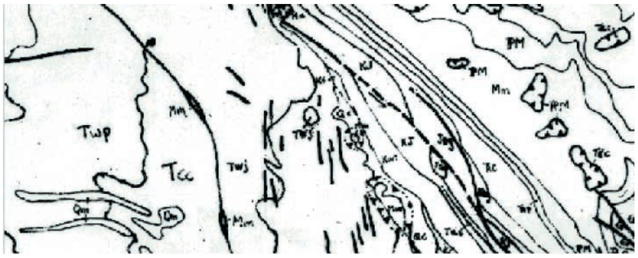


Figure 3. Linework near Pat O'Hara Mountain, southern part of the Cody, WY 1:100,000-scale map.

map? I suggest that lines labeled as contacts be labeled in addition with other information that would add geologic and geometric attributes such as "unit top" or "unit bottom".

Another related question has arisen while capturing the Cody geology. The lines were automatically generated from a cleaned-up raster scan file by LT4X, a raster-to-vector conversion package used currently by the USGS-NMD. To reduce the angularity of such lines, the final vector data set was smoothed using B-splines. The result was that, after the import into Arc/Info, the lines representing contacts, faults, or dikes that had shown the slightest "wiggle" in them as raster lines had too many vertices. However, at map scale, the lines look "good" or smooth.

I am experimenting with the "GENERALIZE" and "SPLINE" commands in Arc/Info. I use the "GENERALIZE" command to eliminate the extra vertices in faults and dikes; and the "SPLINE" command with an appropriate value for the grain tolerance along with the "GENERALIZE" command with the "BENDSIMPLIFY" option to eliminate extraneous vertices in contacts. I am also experimenting with values for the "line simplification distance" option and the grain tolerance. Careful use of the "GENERALIZE" command and the "SPLINE" command should produce smooth contact lines and straight faults and dikes that matches the original linework of the author.

Lastly, in some places, rock units that were mapped separately on the 15' geologic source maps are combined when the outcrops of individual units are too small to be seen at 1:100,000. I have left them as Pierce compiled them. I have done this so that the "art", which is only partially map esthetics, and his geologic concepts would be kept intact.

Problem 2: Map resolution and digital geology

The use of an autovectorizer such as LT4X to convert raster scans of map data to a vector format can introduce extraneous lines as vectors. One problem occurs at line intersections. Line intersections are not always "clean" as a raster scan. As a result, Very Short Lines (VSL), lines less than 50 meters in length (at a scale of 1:100,000) are inserted at some intersections, especially if two lines as pixels meet at a shallow angle (figure 4a). However, line intersections are not the only case where VSLs are found. They also occur in places where line intersections as interpreted from the scan are close together. When drawn on a map and then scanned, lines have an actual width that lines as vectors do not. In order to check for all VSLs, each line that was 50 meters or less in length was selected and displayed on a 1:100,000-scale plot of the line data. I then had to choose to delete the VSL or leave it in no matter what its origin was and perhaps even add to its length so that a later check would not select this line (figure 4b). This latter choice might allow a fault to traverse an area very close to other line intersections without intersecting nearby contacts at nodes and thereby change a geologic interpretation.

The choice of 50 meters for a VSL was in origin a choice based on experience. I have learned since that the NMAS (USBB, 1947) document specifies that 90% of all objects shall be within 1/50th of an inch of the true position when placing objects on a map at a scale smaller than 1:20,000. This corresponds to 50.8 meters at a scale of 1:100,000. A point of confusion may arise because USGS-NMD uses similar terms in the Federal Geographic Data Committee (FGDC, 1998) metadata standard as follows:

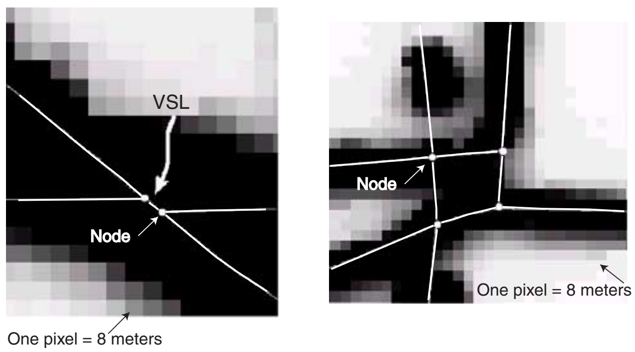
1. Resolution (abscissa and ordinate): means the resolution of the digitizing or scanning device. Since NMD uses digitizers and scanners that have a resolution of 0.001 inches, NMD reports the resolution for 1:100,000-scale DLG data as 2.54 meters. This is not the same as:

2. Positional accuracy: NMD uses NMAS (USBB, 1947).

In addition, the Geography Department at the University of California at Santa Barbara (UCSB) teaches a concept called "map resolution" in their GIS classes. UCSB defines map resolution to be linear distance below which objects cannot be accurately located relative to other objects on a map of a given scale. The rule of thumb taught to UCSB students is as follows:

(Map scale denominator) / 2*1000 = map resolution, in meters.

Then, map resolution would be 50 meters for a 1:100,000-scale map, and 12 meters for a 1:24,000-scale map. More recently, NMD states in the map revision document (USGS-NMD, 1998) that locations of revisions to preexisting maps especially from aerial photography may be in error by as much as 22.2 meters (forty feet) of its actual position on a 1:24,000-scale map. If this is scaled for a 1:100,000-scale map, this positional inaccuracy might be as large as 88.8 meters. Moreover, one might argue that the digital geologic map layer is a revision or an



a. LT4X extraneous VSL **b. Geologic feature of VSLs**

Figure 4. Very short lines shown over original raster scan.

addition to a preexisting map, the topographic map. In this case, the accuracy with which digital geology can be located on 1:100,000-scale topographic base maps may be on the order of 100 meters.

The understanding or lack thereof about these foregoing concepts in this section by the geologic mapping community has great consequences for digital geologic map compilation and its subsequent use as a thematic map layer.

Problem 3: The transfer of digital geologic geometry

The compilation of lines and polygons representing the geology of the Cody, WY 1:100,000-scale map will be done in one layer or coverage. There are advantages to this method of compilation. Lines that have multiple attributes both as linear features and polygon boundaries can be easily edited and updated. Unfortunately, this is not the case for point data. While my study of the features on the Cody materials shows no geologic features to symbolize as points, other 1:100,000-scale geologic maps include such features.

Mappers that I know usually delete rock outcrops that show as a point unless such features are a topographically or geologically important feature. They then “cartoon in” a line or polygon to represent these features. However, Reynolds (1971) used small triangles to indicate formation outcrops that were too small to show on a 1:24,000-scale map. The locations of these outcrops were important data that show the reason that inferred unit contacts were drawn as shown on the map. It is not possible with most GIS systems to use point data formats to represent spatial features in a layer with polygon or line data. For example, any attempt to include data points in an Arc/Info coverage that contains polygon and line data results in problems if one issues a “BUILD” or “CLEAN” command. All of the data points then become label points, and the effect of these commands cannot be undone.

Digital geologic map analysts prefer polygon and line data in the same coverage while working in Arc/Info. However, a “casual” user of ArcView who imports such a map coverage will be surprised to learn that strictly line information may be left behind. In ArcView, line data and polygon data cannot exist in the same file. Other GIS systems do not allow attribution of polygon boundaries with more that one attribute. A line that is a polygon boundary cannot also be a fault in these cases.

The preceding discussion becomes more complex when one looks at existing and proposed standards for the simple geometric terms: polygon and line. The definitions of these terms differ among software vendors and standards organizations. The interested reader can look at some of the various standards listed below:

1. OpenGIS: <http//www.opengis.org/techno/specs.htm>
2. SDTS: <http//mcmcweb.er.usgs.gov/sdts>
3. SAIF: <http//www.elp.gov.bc.ca/~srmb/saif32/>

A possible solution to these problems comes first from asking the question: What type of spatial data geometric objects do modern GIS systems handle best? In my opinion, these systems handle polygons, of whatever type, best. Then notice that USGS-NMD publishes point data in DLG files by including points as lines composed of two vertices that lie on top of one another. These two ideas lead to a further idea that would allow the representation of both point and linear features as polygons.

To represent points as polygons, image a circle whose radius is twice the grain tolerance (in Arc/Info terms) (figure 5a). The circumference could be attributed as a “scratch” line, which means that the circumference of the circle would not be drawn. Marker symbols then could use the label point at the center to symbolize an attribute of the point. Circles of the recommended size would have little effect on the measured area of a containing polygon and would not be seen unless the circumference was drawn. I would call such a structure a “dot”.

Extending the idea to two dimensions (a line), imagine a linear feature that is enclosed by a “flexible” rectangle whose width would be four times the grain tolerance with the line representing the linear feature running down the center of the rectangle (figure 5b). This would make two polygons, one on either side of the central line that could be labeled “right” and “left” to show the direction that the line should be traversed. I would call this construct a “wire”. Problems would arise with the implementation of such constructs, but they would allow point and linear features to be carried in the same coverage in all GIS systems. A wire would allow a linear feature to be clipped and still keep the directional information intact. Linear feature decoration would be applied to the central line without interruption. The perimeter of the wire could be a scratch boundary when necessary. Unfortunately the

"Dynamic Segmentation" feature of Arc/Info that would perform most of the same functions is proprietary and does not directly allow an import into other GIS systems.

The wire construct would be of great value in the geologic map database of the GYA, because there are five different forms that dikes are recorded on geologic maps here (I am including sills in this discussion). They are:

1. Dikes that have a width that can be shown in true size on the map.
2. Dikes that are too narrow to show the actual width, but use a polygon form to keep the geometry of the dike and its relation to other rock outcrops and structures.
3. Dikes as lines. A line may represent more than one dike.
4. Dikes that are too numerous and too small to show individually, but the map compiler wants to show the dike pattern directions and concentration.
5. Dikes that are too numerous and too small to show individually and even the pattern of the dikes cannot be seen, and the map compiler wants to show the presence of dikes.

The wire construct would allow the geometric relations of linear features like dikes and sills of the first three types to be kept in the geometry. The fourth and fifth dike types can at present best be shown as overlay polygons in another coverage. The number of dikes on the Cody 1:100,000-scale map alone discourages the recording of individual geometric relations in an attribute relations table. Such relationships might be more easily recorded in a form that is useable in a digital manner as a part of the spatial geometry of the coverage.

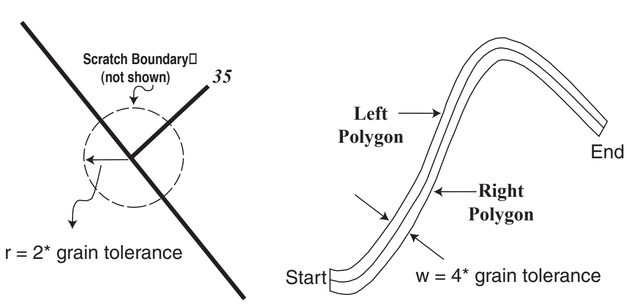
In addition, any solution to the problem of representing spatial two-dimensional data in one coverage will have to fit into a modern storage system that would allow multiple viewers and GIS systems to use such a database. It is becoming clear that this will be an environment that will be a multi-tiered storage and retrieval geospatial data system. Most of the proposed systems involve three major tiers of software. Figure 6 show the OpenGIS approach to the distribution of GIS data. They are:

1. User software – Viewers, editing, and analysis tools.
2. GIS system software – Arc/Info, AutoDesk Map, Intergraph, SmallWorld
3. Relational database with SQL – Oracle, Xybase, Informix

Translating software may be necessary in between each of the three tiers, using the main software systems application programming interfaces (APIs) shown in figure 6, to allow data to move smoothly from one of the tiers to another. With the advent of such systems and the likelihood of GIS data holders moving to this kind of a data archive, the spatial data produced by the geologic community must be in such a form that it will readily be useful in such an environment. This form includes an understanding of the geometric aspects of their products.

CONCLUSIONS

I have digitized and attributed the Cody, WY 1:100,000-scale materials to retain the art, esthetics, and geologic concepts recorded by the map author. I am producing a map database that when rendered as a map will have pleasing line work, and yet be useful to geoscience analysts. The cleanup and attribution of the map data will take into account the resolution of the digitizing method while capturing the source data using map accuracy standards, and the concept of map resolution as presented by UCSB as guides. In addition, digital map files for this product will be furnished in a sufficient number of formats to insure ease of use in a number of common viewers and GIS systems. The attribution of the map and the database



a. "Dot" with a symbol **b. "Wire" as a linear object**

Figure 5. Point and line objects captured as polygons.

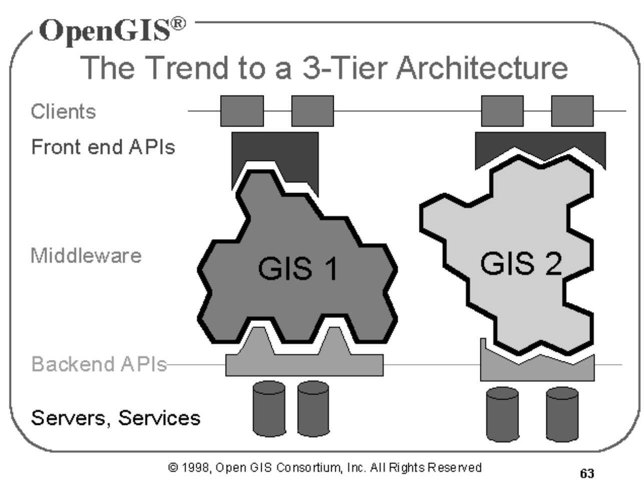


Figure 6. Three-tiered data delivery, with their Applications Programming Interfaces (APIs).

follows the NGMDB data model preliminary standards version 4.3 using the "Curly tool" (Raines and Hastings, 1999) for the data entry and export into Arc/Info. The proposed North American data model standard for geologic maps is available at: <http://geology.usgs.gov/dm>.

The future of the geologic database may be with Arc/Info version 8 on Windows NT systems using object models or with GIS systems like SmallWorld or even by the use of polygons to represent all geologic information in current GIS systems. A continuing study of current spatial geometry standards by one of the current AASG/USGS working groups or a new working group is needed to see how these spatial geometries fit the needs of digital geologic maps. Clearly much remains to be done to standardize digital geologic map geometry.

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Geomatter: A Map-Oriented Software Tool for Attributing Geologic Map Information According to the Proposed U.S. National Digital Geologic Map Data Model

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INTRODUCTION

GeoMatter (Geologic Map Attributer) is a prototype data entry tool that enables the population of databases structured in the proposed U.S. national digital geologic map data model format (Johnson and others, 1998). It was developed by Geological Survey of Canada to facilitate geologic map data entry as well as explicate the data model. Users are expected to have in their possession a digitized version of their geology in ESRI's shape file format, and an empty (or not) MS-Access database conforming to the data model version 4.3, prior to using the software. GeoMatter provides a graphic environment where the geological map and its underlying database coexist on-screen during data entry. Database contents are linked to map objects and this provides the map not only greater information content but also defines its cartographic appearance. Once linked, the map and database remain synchronized, such that selecting an item in the database causes related map objects to be highlighted, and vice versa. GeoMatter thus both expedites data entry and facilitates information browsing. It is designed to host multiple map products within its map database. Its usage should result in digital geologic maps that are complete in terms of cartographic appearance, relatively deep in information content, and compliant with a common data standard. This will aid field mappers in creating digital map products, map compilers in integrating map products, and corporate entities in managing and distributing geologic knowledge in map form.

Software

GeoMatter is a stand-alone product that requires no other software to function. It comes with a standard Windows install and un-install script that manages the addition and removal of the program. The end-user is responsible for establishing a connection (via ODBC – Open Database Connectivity) to an appropriate database (e.g. MS-Access) and for making the map layers available by copying them into an appropriate location. A bare-bones user's manual is provided to aid its usage. It differs from other mapping packages, such as ArcView, in its ability to manage a complex geological database and in coordinating maps with it.

GeoMatter follows in the footsteps of other prototype data entry tools, most notably Curly (Raines and Hastings, 1998) and LegendMaker (Sawatzky and Raines, 1998). It differs from these approaches in three main ways: firstly, in the coexistence and tight integration of the map and database; secondly, in its user interface which insulates the user from the underlying database structure; and thirdly, in its inability to adapt to major design changes in the data model without additional programming.

Hardware

GeoMatter operates on standard Windows 95 or NT computers. In its current state, disk related operations are particularly slow, and require at least a powerful Pentium II microprocessor and large quantities of memory (e.g. at least 64Mb) for adequate performance. These and other shortcomings will be remedied in a forthcoming revision.

Distribution

GeoMatter is currently at a prototype stage due to technical development issues and, in part, due to the evolving nature of the data model. Its main functions are operational but with much embedded quirkiness. It has therefore not yet been applied within a serious map compilation project, and this will likely remain to be the case until the currently planned revisions are completed. Experimentation with the product is currently limited to partners within the data model effort who contact one of the authors for 'as is' access to the software and manual.

Future Directions

GeoMatter is currently being revised and completed for production usage. Many current deficiencies are being corrected and some necessary functionality added, such as full compliance with v4.3 of the proposed U.S. national geologic map data model. It is anticipated that this work will be complete in fall/winter 1999.

The discussion below touches on some historical aspects of GIS software development that impacted the creation of GeoMatter, followed by a description of the user interface and its interaction with the proposed U.S. national digital geologic map data model.

DATA MODELS AND THE NEED FOR APPLICATION SOFTWARE

The establishment of a standard data model for digital geologic map information is a critical component of the national map database initiatives in the US (Soller and Berg, 1997), Canada (Broome and others, 1998), and elsewhere (Bain and Giles, 1997; Ryburn and O'Donnell, 1998). Designers of these data models are faced with a daunting task in that the complexity of geological information requires equally complex database architectures: it is inconceivable to imagine that the computer representation of a complex earth system would be significantly simpler without great loss of context, content and, ultimately, utility. Mature data model efforts in the geosciences (POSC, 1998; PPDM, 1998) reflect this reality, being composed of hundreds of interrelated parts, such as tables in relational databases or objects in object-oriented systems. Often these parts do not reflect actual geologic elements but are artifacts of the computing system being used. It is therefore understandable why end-users feel lost in the maze of one data model or another and are reluctant or unable to populate these complex structures that seem foreign and removed from their view of the world. In database technology this conflict between how reality is represented by the computer versus the user's perspective has been long addressed and solved: application software presents the database to the user in distinct views (Date, 1990) that coincide with the user's conceptions, and the underlying data structures remaining hidden. Intermediary software is thus expected to mediate between user and database. To aid this process the database community has evolved CASE (Computer Assisted Software Engineering) tools that greatly ease the construction of application software from initial database design. Indeed, these are so mature that the database and application software design processes seem as one task within such environments, as the tools generate both a database structure and accompanying application software.

In GIS however, we are only now beginning to see the emergence of sophisticated tools for application software development. Partial responsibility for this lies in GIS' relative immaturity; however, it is also probably due to the fact that GIS explicitly deals with the added complexity of spatial information which possesses no unifying theory (Edwards, 1996; Frank and Kuhn, 1995), leading to disparate, often conflicting, implementations (Gahegan, 1996). Although several ad hoc data exchange standards such as DXF (AutoDesk, 1999) and government led efforts such as SDTS (USGS, 1994) and SAIF (Canadian General Standards Board, 1995) have come into existence, they are not theories of spatial computation in the same sense that the relational data model defines relational data management or that object-orientation defines object computing. Emerging spatial standards (Open GIS, 1998; ISO/TC 211, 1998) improve this situation to a degree, but they are also immature and, arguably, incomplete, and have not yet engendered viable software application environments. On the other hand, the explosion in the usage of object-oriented programming, and its subsequent recent adaptation by the GIS community, has caused individual vendors to forge onwards and create spatial tool kits that are powerful albeit diverse. The challenge in developing effective spatial database software now rests in sifting these various vendor offerings for a suitable match to the problem at hand.

DESIGN OF GEOMATTER

The proposed U.S. national digital geologic map data model is at once both a conceptual and logical representation of a geologic map. It is *conceptual* in that the fundamental components of a geologic map (as understood by the designers) have been abstracted for computer representation independent of any database implementation. This is expressed primarily in the descriptive text of Johnson and others (1998). The remaining text and diagrams of the report are oriented to a relational database description of these concepts and in this way constitute a *logical*, technology-specific, expression of them. When the logical design is applied within a specific relational database system, such as Oracle or Access, the resultant configuration represents a *physical* model.

For the software designer these distinctions can be very useful, and can in fact become the basis for the design of application software. The conceptual elements that comprise a map (e.g. legend, text, map features, etc.), being user-oriented, provides a good basis for a user-interface, whereas the logical and physical aspects (i.e. the relational database design) provide a foundation for the underlying data repository. For instance, if software designers choose to adopt SQL (Standard Query Language) as the language for manipulating relational databases in their programming, then they have in effect enabled their software to operate with any database that is SQL compliant. This illustrates the *logical-physical* division, as the logical SQL part is syntactic and unchanged across hardware environments, whereas the databases that respond to SQL must differ internally to cope with different *physical* hardware platforms—thankfully, in a way that is largely transparent to the user.

From this we can envision a software tool that presents a geological user interface (*conceptually*), communicates to its data store via SQL (*logically*), and permits connection to a variety of relational data repositories (*physically*). This is essentially the design of GeoMatter. In executing this design, the Delphi object-oriented programming environment was used to enable rapid development of the user interface and to facilitate its connection to the underlying relational databases via SQL and ODBC; ESRI's MapObjects component (ActiveX) was used for map display, symbolization and various spatial operations.

USER INTERFACE

Following the data model design, the user interface is organized around six main concepts: sources, legend, rock unit, structural unit, occurrence and map (spatial objects). GeoMatter permits relevant information to be added to these components and enables linkages between them to be established. It is designed to accomplish this in a way that is familiar to the geologist by mimicking the traditional map construction process. The map is drawn on one or more layers that host geological boundaries and associated geologic features. These are given meaning by relating geological information to them through a legend that also determines their cartographic appearance. Hence the map takes shape by defining a map Legend which contains symbolized Rock Units, Structural Units or Occurrences, which in turn are then connected to a map description in the Sources and to specific map features on the map face.

These activities take place in two main windows (Figure 1): an information window on the left, where the text information is managed, and a map window on the right where the map is displayed. A geologist can therefore maintain the map display and simultaneously browse, add and edit information about specific map features. Moreover, focus is maintained throughout, such that as a specific item is chosen from the map or from the database, all related map and database items are selected and highlighted, thus enabling the geologist to quickly view interrelationships among them. For example, if an item in the legend is selected by the user then its related map objects are highlighted on the map, and its associated map definition, rock units, structural units or occurrences are selected and displayed within the individual information components.

Sources

The *Source* component (formally known as *Metadata* in v4.2—Johnson and others, 1997) is a repository for document descriptions that are cited in other parts of the database. These could be maps and reports or any other document that needs to be referenced within the data model. Sources can be browsed, added and deleted here. Selecting a source that has a legend associated to it will cause the map to be symbolized according to the attached legend. This capability has interesting ramifications as it allows derivative map products to be created and stored, as several legends, and thus many map sources could be associated with any one set of geographic layers. For instance, the spatial objects in the map window could be represented as a bedrock geology map, a tectonic unit map, a dominant lithology map, etc., each having a unique legend in the Legend section and unique reference entry in the Source section. Viewing the objects in the map window according to any one theme simply requires the appropriate reference to be selected. Since the various sections are linked, browsing the data contents thereafter will result in the highlighting of information specific to the selected theme (e.g. tectonic units or lithologies instead of bedrock units). The ability to display different map layers in the map window, permits users to manage multiple map products from one database. Note that map layers are only displayable and not editable – GeoMatter is not a digitizing tool and does not currently allow map features to be modified, though this might change in the next version.

Legend

In many ways the Legend component is the heart of GeoMatter. It effectively acts as a visualization device, coordinating specific data content, symbolization, and spatial objects to form a 'map'. Thus, although in appearance it resembles a typical geologic legend, it in fact best illuminates a nontraditional implication of the data model: that a map is simply a specific view of a geologic database, defined by the collection of specific symbolic, thematic and spatial parts. It is thus possible to rearrange these components and arrive at a different map from the

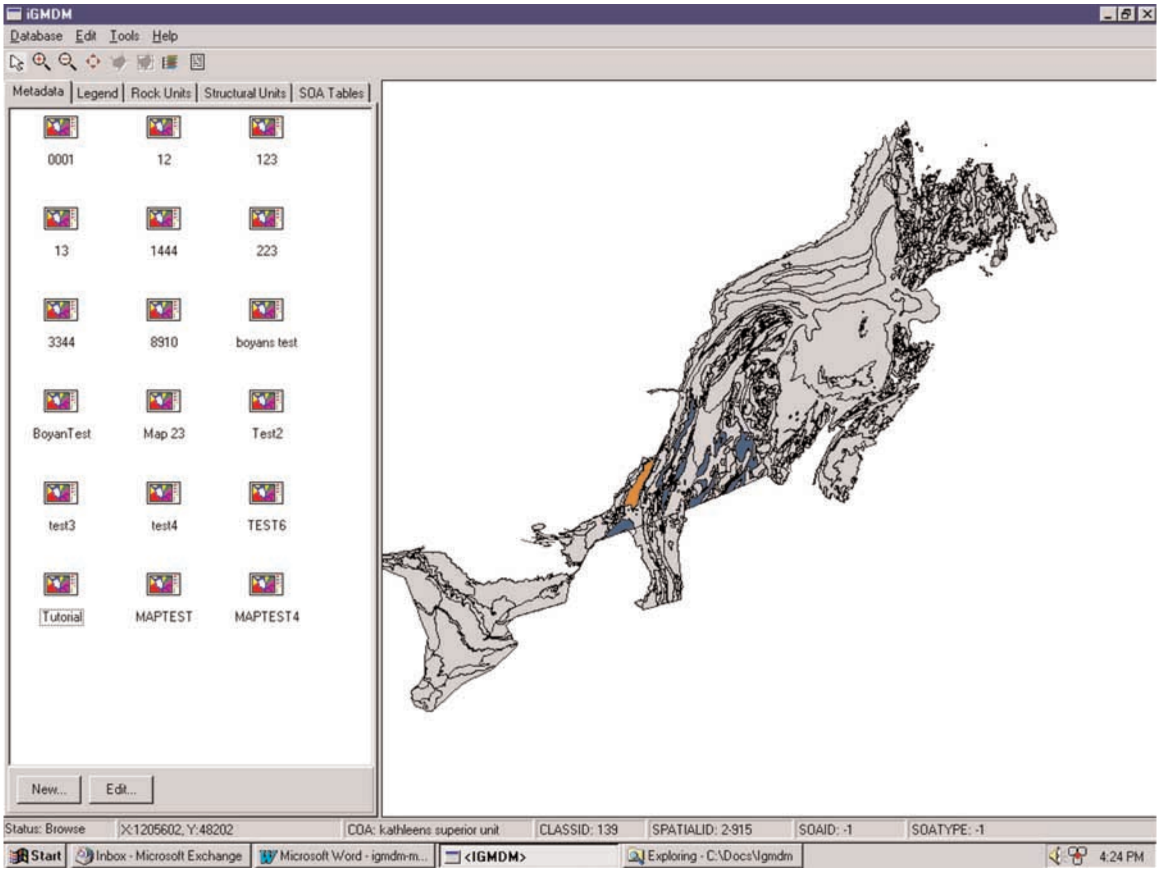

Figure 1. The GeoMatter interface — an extensible database window for geologic information is situated on the left, and a window for displaying the map layers is found on the right. The database window is displaying the Source component, which lists the available maps and permits their selection and modification. Once a map is selected, the map layers acquire cartographic and geologic characteristics.

same pool of data. This amounts to classifying a set of spatial features according to different Legends. As a Legend can only be related to a single map Source, GeoMatter requires a new map Source to be defined before another Legend can be ascribed to the same map features.

A Legend is displayed as a list of individual items (Figure 2), each containing a symbolization and thematic description. The Legend provides efficiencies in editing and browsing map data. Individual map objects can be selected from the map and assigned to a legend item. In browse mode, selecting a map object will cause its legend item to be highlighted, or vice versa, the selection of a legend item will cause all associated map objects to be highlighted, making very clear the distribution of that item on the map.

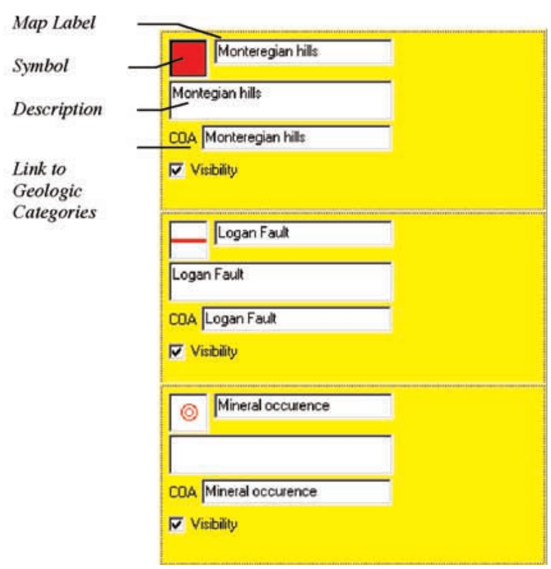

Figure 2. Part of a Legend. Each legend item contains a symbol, map label, text description, and a link to a geologic category. Objects on the map can be assigned to a legend item, and will thereby inherit the cartographic and descriptive characteristics represented by the item.

Rock Units and Structural Units

The geological data model differentiates between categories of geologic information (COA — Compound Object Archive) and specific instances of geologic occurrences (SOA — Singular Object Archive). For example, a specific structural measurement occurrence has a unique identity and defining characteristics (e.g. position, strike, dip), but belongs to a general category (e.g. foliation); likewise ‘fault’ is a generic category whereas the ‘Logan fault’ is a specific instance of the general category. This is very analogous to the geological mapping process where the geologist abstracts a generalized category, call it ‘map unit’, from a set of descriptions located at specific occurrences.

The Rock Unit and Structural Unit components represent the list of available categories within the system. Rock Units typically characterize polygons and Structural Units linear features, but this is user-driven as GeoMatter will allow any geometric shape to be attached to a rock unit, structural unit or occurrence. The category lists may be arranged hierarchically (Figure 3a) to follow geological relationships: e.g., a formation contains members and may be contained within a group. Mechanisms are provided to modify the hierarchy (Figure 3b) and to alter the level of detail displayed. Individual categories may be further described according to their rank (for rock units), geochronologic age, stratigraphic age, rock composition and their relationship to other units (e.g. overlying, contemporaneous, etc.). Specific hierarchic lists are incorporated at the appropriate places during data entry, to control the content of certain database items, such as rock type terminology. As with the Legend component, selecting a unit will highlight its occurrences on the map, and vice versa, selecting a map object will highlight its associated category in the units’ list.

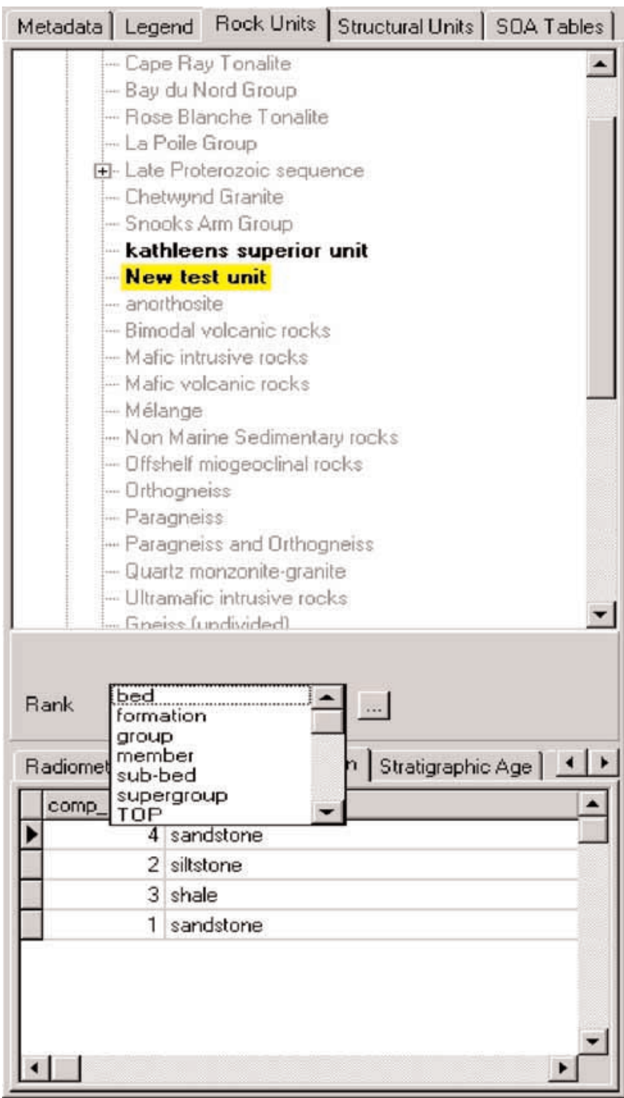

Figure 3a. The rock unit tab contains a hierarchy of rock unit categories and their lithologic composition and age descriptions.

Occurrences

Fossils, structural measurements, mineral deposits, and individually named plutons are examples of occurrences that can be described by GeoMatter. In addition, specific map units (e.g., polygons) can be assigned proportional compositions of lithologies or other map units. Again, this follows the mapping process where a general category is a best fit description of the occurrences leading to its inception; unless these occurrences represent a type locality for the category they will likely differ somewhat from it. For example, a map unit may contain mostly shale, then silt and sandstone, but a specific occurrence (e.g., a polygon) may contain only a subset of these in varying proportions.

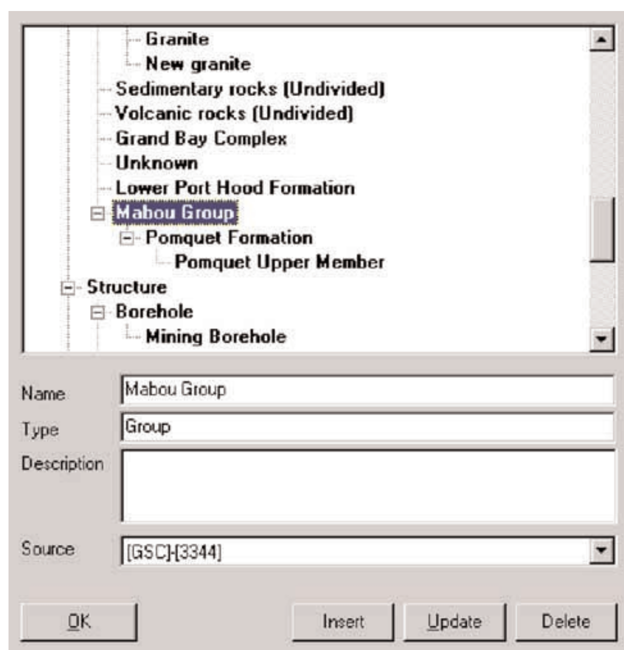

Figure 3b. Modifying the rock unit hierarchy. Rock unit categories can be added, deleted or moved.

CONCLUSIONS

GeoMatter could be used by any geologist interested in boosting the information content of their existing digital geologic map. It is designed to enable the assignation of cartographic and geologic attributes to digitized points, lines or polygons, and to browse resulting map database contents. This should enhance the information content of digital geologic maps and thus aid the usefulness of individual map products and promote the construction of broader map databases whose contents are interchangeable. It should particularly benefit map compilers interested in facilitating the integration of diverse map products by standardizing on one database structure. The latter might include not only individuals but also organizations developing corporate map databases for internal usage or external distribution.

Underlying all such activity must be the belief that scientific understanding will be advanced through the synthesis of information that was previously difficult to integrate. Developing effective tools that will aid the population of interchangeable databases becomes imperative to this effort, and it is in this regard that GeoMatter hopes to make an impact. At the moment it is a prototype effort that will soon be upgraded to a system capable of being utilized in production mode.

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Development of the Kansas Geologic Names Database: A Link to Implementing the Geologic Map Data Model Standards

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INTRODUCTION

The Kansas Geologic Names Database (NDB) is a relational database of stratigraphic nomenclature. It has evolved, with extensive modification, from the text files of the recently published *Lexicon of Geologic Names of Kansas (through 1995)*, edited by Baars and Maples (1998). The NDB development process has proved to be a valuable and practical aid toward implementing the digital geologic map data model (MDM) proposed by Johnson, Brodaric, and Raines (1998) through the National Geologic Map Database (NGMDB) Project. In particular, the nomenclature database facilitates development of the tables for Kansas related to rock unit definitions within the MDM. It is applicable to stratigraphic nomenclature appropriate to geologic maps and other reports on the geology of Kansas published currently or at any time in the past. When dealing with previously published maps, the nomenclature database links rock unit names in use at the time of publication with both prior and subsequent variations in accepted nomenclature, and with the sources of those changes. This paper reviews development of the nomenclature database and its associated data model, the influence of this project on development of a geologic map data model for Kansas, and variations from the data model of the NGMDB Project.

OBJECTIVES AND MOTIVATION

The primary goal of the nomenclature database project is the organization and enhancement of information from the Kansas *Lexicon* into a form that permits easy access to descriptive information on rock units based on a wide and flexible range of user needs and selection criteria. One geologist may be interested in the current nomenclature of the formations within the Admire Group (Upper Pennsylvanian, Virgilian Series), along with the locations, descriptions, and available images of their type sections. Another geologist's interest may focus on the accepted nomenclature for the Admire Group prior to 1938 (then considered Permian) and its relationship to the previously defined "Admire shales." Someone studying the history of geologic research in Kansas might want a list of all rock units first described in publications having R. C. Moore (a former state geologist) as principal author.

Numerous other goals are tied to flexible access to rock unit information. It is clearly desirable to link descriptive text files for a specific rock unit to corresponding digital map objects, photographs, or document images. On-line edit capabilities permit easy correction of errors found within the nomenclature database, with immediate display of corrections to users. A capability for publication on-demand directly from the database permits prompt, cost-effective publication of enhanced or specialized lexicons as information within the database is improved.

Geologic mapping, broadly defined, is the fundamental data collection and information management activity of the geologist. With the rapid pace of digital geologic map data development in Kansas, the nomenclature database is needed for direct support of mapping and related publication activities. The importance of the nomenclature database for implementation of the NGMDB Project's proposed geologic map data model standards became apparent in the early stages of the project, with recognition that the proposed standards had much to offer toward design of the nomenclature database. Both efforts are viewed as a step toward development of a general model for all geologic data, as suggested by Richard (1998).

Many of these objectives arose in direct response to shortcomings of the *Lexicon*, which was developed in a word processing environment. The *Lexicon's* digital text files lack organized database structure and are not publicly accessible. By its nature, a lexicon of stratigraphic nomenclature is characterized by repetitive use of a limited set of information types. Contributions to the *Lexicon* from numerous stratigraphers, combined with the large number of included names, contributed to inconsistent style, format, and information content for named units. Use of abstracts from earlier lexicons perpetuated previously published errors. This practice also resulted in frequent occurrences of citations with imbedded references to sources described by author, date, and page with no further identifying information to be found anywhere in the *Lexicon*. In its printed form, the *Lexicon* provides no visualization of type sections or the geographic extent of named units. Direct support to digital mapping activities is not practical with the structure of the *Lexicon's* text files. In an effort to conserve space and limit the publication to a manageable size, a considerable amount of useful information was excluded from the *Lexicon*.

THE NDB DEVELOPMENT PROCESS

Given the objectives of the geologic names database project, relational database capabilities clearly offered a practical means of addressing the task at hand. In a critical first step, the original Lexicon text files were reformatted to facilitate parsing into separate fields. Significant revisions and enhancements occurred as information contained in the original files was checked for errors and omissions.

As development proceeded, it became apparent that similar data structures were appropriate for management of digital geologic map data and for management of historical information about the names of geologic rock units. Information on digital geologic map data models available through the NGMDB Project web-site <http://ncgmp.usgs.gov/ngmdbproject/> simplified the development process. It provided a clear starting point, identifying critical tables, data fields, and relations.

An iterative process was implemented to achieve a balance between the additional effort of working around more problems in the full text files and the additional gains from further identification of useful text segments prior to parsing and loading into the relational database. Once that balance was reached and parsing routines were thoroughly tested, the information from the enhanced and reformatted *Lexicon* files was parsed and loaded into the relational database management system. A large portion of the information went into three tables of the new NDB; the SOURCES, CITATIONS, and ROCK_UNITS tables (Figure 1). There are one-to-many links from SOURCES to CITATIONS (each source may have citations relating to many different rock units) and many-to-one links from CITATIONS to ROCK_UNITS (where citations from many sources may define a particular rock unit). Further parsing, as needed, will be done within the relational database management system.

The SOURCES table contains a separate record for each unique information source. There are 914 sources currently identified in the NDB. Records contain basic bibliographic information, source format (book, journal, note, map, etc.), and (where appropriate for specific geologic reports) information on the geographic extent of the study. A recursive source relationship ("contained in") is built into the SOURCES table. One source may contain many other sources. For example, an issue of a journal may contain many articles. Currently, 186 sources are identified as "contained in" 97 of the other sources. Records within the ROCK_UNITS table provide the basic identifying information for each recognized geologic rock unit name. This includes name, name origin, lithostratigraphic or chronostratigraphic rank, the names of each unit of higher rank containing the original unit, text statements of geographic extent and pointers to map objects for visualization of geographic extent. There are 1820 unit names in the database, including about 250 chronostratigraphic names and 1570 lithostratigraphic names. Fewer than 500 of the lithostratigraphic names are currently accepted as formal names in Kansas. A recursive unit relationship ("current_usage") is built into the ROCK_UNITS table to link abandoned unit names to the currently accepted nomenclature for the corresponding unit. Each record of the CITATIONS table, linking SOURCES and ROCK_UNITS, contains descriptions or comments regarding a specific rock unit, obtained from a specific source,

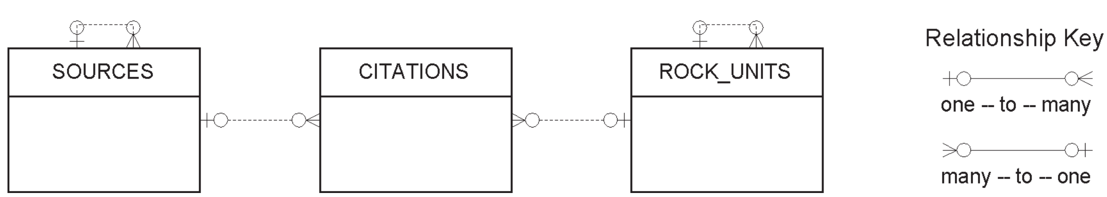

Figure 1. Primary tables in the NDB, reflecting the interface of information sources and defined rock units with specific citations.

with reference to the specific location of the information within that source. There are 5179 separate citations; an average of 2.8 citations per named rock unit.

The overall structure of the digital geologic map data model (MDM), as presented in Figure 2-6 of Version 4.3 (Johnson, Brodaric, Raines, Hastings, and Wahl, 1998, p. 7), is generalized here in Figure 2. The model has four major components. The METADATA section provides detailed information about the information sources (i.e., data about data). The SOURCE table is the primary table within the metadata section of the MDM. In the MDM the sources are typically either published maps, sources containing the published maps, or the documents and databases from which the published maps were derived. The COMPOUND OBJECT ARCHIVE of the MDM provides data structures for information related to all complex geologic features found in the real world, including a rock unit table and related descriptive tables. The SPATIAL OBJECT ARCHIVE section maintains data on map objects used in visualizations of particular rock units. The LEGEND, with associated classification schemes, provides the functional details for specific map visualizations achieved through the combination of spatial object representations of rock units.

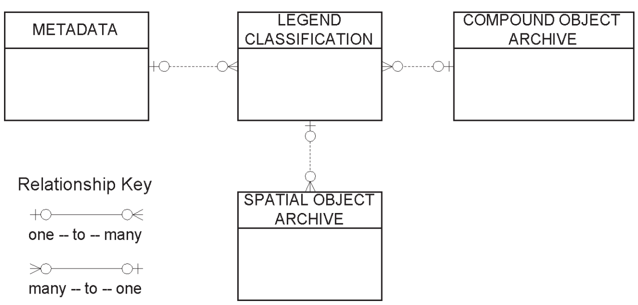

Figure 2. Generalized structure of Version 4.3 of the digital geologic map data model (Johnson, Brodaric, Raines, Hastings, and Wahl, 1998).

A more detailed view of the metadata portion of the NDB is provided in Figure 3. These tables provide information collectively describing the origins and nature of available geologic information. They correspond to the metadata tables of Version 4.3 of the MDM.

A separate AUTHORS table has been added to facilitate access to work by particular authors in the NDB. An intersection table (X_AUTHORS_SOURCES) links authors to each of their publications, identifies their sequence in a list of contributing authors, and links the author to their employing organization for that publication. Sources are linked to publishing and funding organizations through a separate intersection table (X_SOURCE_SUPPORT). This permits many-to-many relationships between funding agencies and information sources, and between publishers and information sources, to be handled as compound one-to-many relationships. The SOURCES_RELATIONSHIPS table links sources within the SOURCES table through relationships such as "complies with [the specified standard]" or "digitized from [the specified source]" as defined in a data dictionary. The PROJECTIONS table provides the additional information unique to information sources with map formats.

Details of the portion of the NDB corresponding to a compound objects archive are seen in Figure 4. The "Formal Unit" and "Rock Unit" tables of Version 4.3 of the MDM are merged into a single ROCK_UNITS table in the NDB. Sequences of units appropriate to a particular map, or published in a specific source as "formal" units at

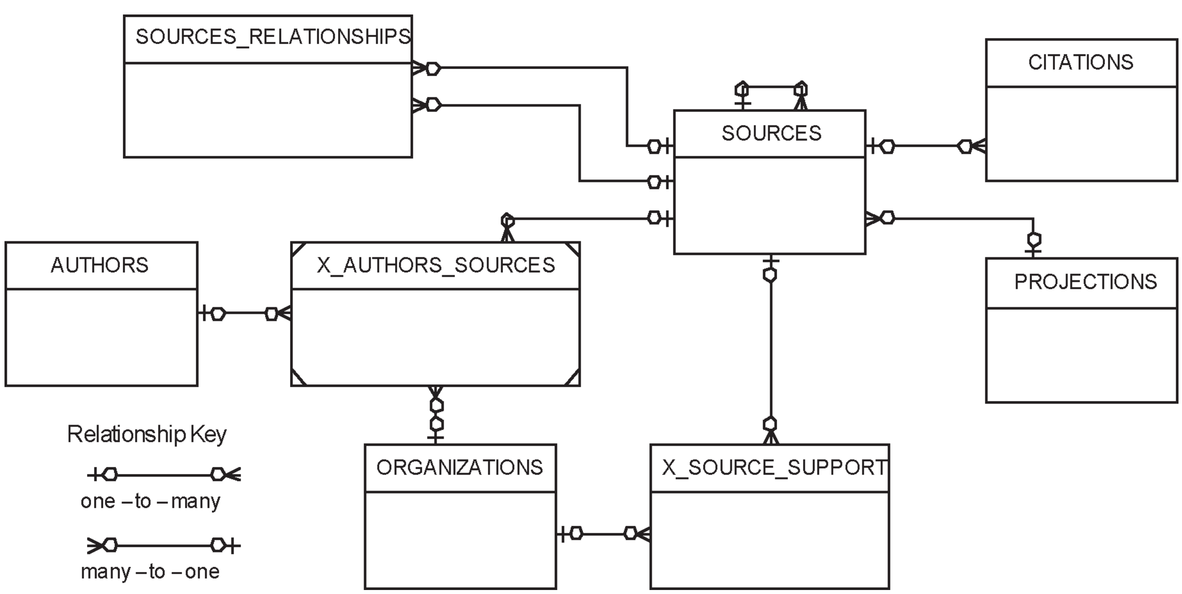

Figure 3. Metadata tables in the NDB, describing the origins and nature of available information.

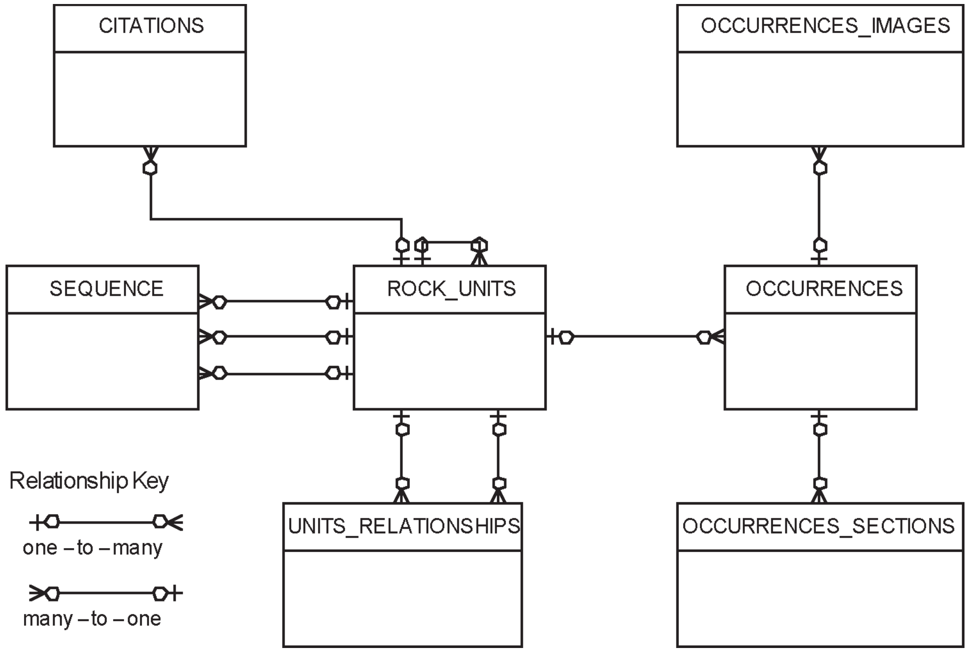

Figure 4. Rock unit tables in the NDB, providing descriptions and relationships of rock units.

a particular time, are listed in the SEQUENCE table. Records in the OCCURRENCES table give specific locations where a rock unit has been described, ranging from the defining holostratotype (original type section) of a rock unit to a local measured section that includes all or part of the unit. The OCCURRENCES_IMAGES table provides pointers to map objects, digital photographs, or scanned records (such as the published type section or a measured section) related to an occurrence of a rock unit. The OCCURRENCES_SECTIONS table is presented here in place of the full range of descriptive tables found in Version 4.3 the MDM. Searchable data related to lithology, composition, fossil assemblages, thickness and other classifying characteristics of a rock unit would be found here, separate from general descriptive statements found in the CITATIONS table. The characteristics found under the OCCURRENCES_SECTIONS table and the relationships found in the UNITS_RELATIONSHIPS table are defined in data dictionaries covering the full range of relationships (hierarchy, classification, correspondence, proportion, and disposition) described by Richard (1998).

STATUS

The design of the Kansas Geologic Names Database is consistent with the corresponding elements of the proposed geologic map data model standards, and represents a major step toward full implementation of those standards. Functions defined in tables in the LEGEND portion of Version 4.3 of the MDM (see Figure 2), control production of visualizations of geologic map data. Similar functions are defined for the NDB using commercial report writer software (available either as components of the relational database management system, or as separate systems) to control report generation for a complete and current lexicon of geologic names in Kansas or selected subsets. For example, a lexicon could be extracted from the database for geologic names used by Moore, Jewett, and O'Connor (1951) in their geologic map of Chase County, Kansas.

Universal web access is now under development. A revised lexicon of geologic names in Kansas will be published on-line at the Kansas Geological Survey's web site <www.kgs.ukans.edu>. The on-line publication will accompany a web conference site of the Kansas Nomenclature Committee for discussion of nomenclature issues, contributions of new information, and reporting of errors within the database. This will be similar to the web conference site used for discussion of the geologic map data model standards by the AASG/USGS Geologic Map Data Model Working Group at <http://geology.usgs.gov/dm/>.

Merging the NDB with the MDM will result in a geologic data model with sources (for particular nomenclature citations) as attributes of spatial objects used to represent specific rock units within a particular visualization of regional geology. The concept of a geologic names database can be broadened to include the historical development of accepted names for specific occurrences of structures or other geologic features in addition to rock units.

CONCLUSIONS

(1) The high degree of effort required to publish complete lexicons of geologic names by the traditional printing

process, accommodating a relatively small proportion of new or revised names, has made such tasks a low priority for most geologists.

(2) Consistent formats throughout large printed volumes (almost impossible to achieve as a manual process and still not easily obtained using word processing software) become feasible in a relational database environment.

(3) Books, including lexicons, are just like published geologic maps — you always discover important omissions and uncorrected errors after they go to press. The larger the press run, it seems, the more numerous and significant the errors.

(4) On-demand publication and distribution from relational databases provides a more efficient and cost-effective method for geological surveys to maintain formal lexicons and provide access to information on geologic nomenclature.

(5) Universal, on-line, access provides strong incentives for geologists to participate in the contribution of new information or identification of errors within the database by limiting their involvement to productive activities and providing rapid incorporation of contributions into the public domain.

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From Functional Analysis to CD — Digital Compilation of the Timmins Map Sheet, Abitibi Greenstone Belt, Ontario

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INTRODUCTION

In 1995, the use of computer technology for making maps was increasing in the Mines and Minerals Division of the Ontario Ministry of Northern Development and Mines. In addition, the Ministry had, by this time, embarked on a massive data conversion project known as the Earth Resources and Land Information System (ERLIS) to make information available on a central system. Different GIS solutions were adopted and implemented throughout the Ministry resulting in a plethora of applications, each with a set of characteristics that met the needs of each section. The cartographic unit of the Publication Services Section (PSS) had migrated from the paper world to using Intergraph as its mainstay in map production. The Data Services Section (DSS) built ERLIS around Genasys Genamap GIS and Oracle DBMS. The Ontario Geological Survey (OGS), a branch of the Ministry of the Northern Development and Mines, had also implemented various software tools. The Precambrian Geoscience Section (PGS) used AutoCAD and Fieldlog as their data entry and map creation software. The Sedimentary Geoscience Section (SGS) used Microstation as their key, drafting tool. Together the PGS and SGS used IDRISI and MapInfo for GIS related work. Despite the variety of applications, the Ministry created an efficient cartographic process that generated quality, hard copy color maps in an on-demand format.

With the initiation of the Abitibi Compilation Project the OGS decided to assess the usefulness of a full-blown GIS package capable of integration, compilation, analyses and exchange. To assess the degree to which this functionality was required, the OGS embarked on a "Functional Analysis" under the guidance of the Data Services Section. Following the Functional Analysis, a formal evaluation of several GIS platforms was completed and a GIS system that best satisfied the OGS Information Technology requirements was purchased.

Using the procedures developed in the Functional Analysis, compilation of the Timmins sheet took place and both a paper colored map and digital product were published in March of 1998. This product represents sheet one of a four-sheet product with the remainder slated for release by 2000.

GEOLOGICAL OVERVIEW

The Abitibi Subprovince is an 800 by 300 km Archean "granite-greenstone" domain. The value of mineral production from this area is the highest in the province, approaching 1 billion dollars (Cdn.) (Thurston 1996). It is dominated by supracrustal and granitoid rocks that range from 2.67 to 2.75 Ga (Jackson and Fyon 1991). The Timmins map sheet covers an area of approximately 9000 sq. km., centered on the Timmins mining camp. Rocks are classified on the basis of their dominant lithology using textures, structures and composition. Preliminary geological information was compiled from previous mapping. New interpretations of the extent of lithological units, specifically in the areas lacking outcrop, greatly benefitted from the use of the reprocessed geophysical data (Gupta 1995, 1996). As well, geochemical data allowed for further subdivision of the geological stratigraphy.

Within the confines of the Timmins map sheet lies the Porcupine mining camp, one of the preeminent lode gold mining districts in the world. Significant base metal production has also come from this area, mainly from the Kidd Creek deposit. Komatiite-associated nickel deposits have been mined intermittently. Non-metallic minerals such as scheelite, asbestos and talc have also been extracted.

STANDARDS

This digital cartographic process required the development of symbol libraries. With these symbol libraries, the OGS has been able to provide clients with a common look and feel to published maps. To date, the OGS has developed a library of over 1600 bedrock mapping symbols that represent features such as sedimentary and volcanic bedding, layering, unconformities, structural features, etc. (Jackson et al, 1995; Muir 1995).

Concurrent with the Abitibi Compilation Project, the OGS continued development of digital line standards, mineral deposit symbol standards and symbol standards reflecting zones of alteration and deformation (stipple patterns). Other libraries under consideration include symbology for metallogenic classification, Quaternary geology and mineral commodity classification. The development process for each symbol library requires considerable effort. In an effort to decrease development time, the OGS has requested symbol libraries from other provincial, state and federal surveys.

To make effective use of symbol libraries in our GIS compilation, it is necessary to port existing libraries over to the GIS environment. Symbol libraries up to this point had only been developed for the CAD and cartographic environment. Off the shelf font creation software was used to create comparable symbols for the GIS environment. Symbols were converted on an "as required" basis. Eventually, symbol libraries will exist in both CAD and GIS formats. Pending the publication of standard OGS symbology for mineral deposits, the Abitibi Compilation Group adopted and modified the GSC mineral deposit symbology (Eckstrand et al, 1995). This symbology, though acceptable, does not classify based on metallogenic processes, a desired requirement of the OGS.

Digital line standards have been developed to reflect folds, faults and contacts. These standards will be incorporated into further releases and the final release of GIS products by the Abitibi Compilation Project.

BUSINESS FUNCTIONAL ANALYSIS

The use of digital technology and geographic information systems (GIS) for geological compilation requires more than the purchase and installation of computer systems. In order to be successful, the adoption of new technology must be carried out with a new perspective of, and more importantly, a new approach to doing business. In the case of the Abitibi compilation, this implies that instead of treating the compilation as a conventional mapping exercise, we have to look at it from the perspective of spatial information management. In other words, the task must be completed using the concepts and techniques for database and information system development, rather than as a sequence of loosely connected assignments in a traditional geological compilation project.

Database development usually starts with the process of a business functional analysis. The objective of the analysis is to develop a business model of the organization (e.g. the OGS) or the specific function at hand (e.g. the Abitibi compilation). This business model depicts all the processes involved in completing the business function and is used as the basis for the following objectives:

(1) to identify the information products (maps, graphs, charts and written reports) produced in the business function;

(2) to identify the data required to produce the information products in (1);

(3) to find the sources of data identified in (2); and

(4) to develop a strategy and procedures to evaluate the suitability of the data in (3) if they are available; or

(5) to develop a strategy and procedures to collect new data to meet the requirements of the data in (3).

There are various ways by which the business processes can be identified. The most commonly used method is to adopt a top-down approach in which business processes are identified and continuously decomposed until individual processes can be completed in one single activity or step. The result of this phase of the analysis is documented in the form of a Business Functional Hierarchy. An accompanying document, called Function Definitions, is then developed. The purpose of the Function Definitions is to explain in detail each of the processes (Figure 1). These two documents are used in the next phase of analysis to identify the information products generated by the business processes, which are documented in a Function-Information Product Table (Figure 1, Table 1). In the next phase of the analysis, the sources of the data are identified and documented in an Information Product-Data Table (Table 2).

In the field of database management, there are different ways by which business functional analysis can be carried out. A popular approach appears to be the Joint Application Design (JAD) methodology (Figure 2), originally developed by IBM as the corporate standard for systems development. This method is based on the core team (also known as focus group) approach. A core team is made up of a facilitator, usually a systems analyst, and a group of five to seven members who are very familiar with the operation of the business. Other members can be coopted from time to time. These include: (1) professional and technical staff who are familiar with the operation of the business but do not have the time to attend all meetings; (2) specialists in certain aspects of the business who will be invited to give expert opinion in certain meetings;

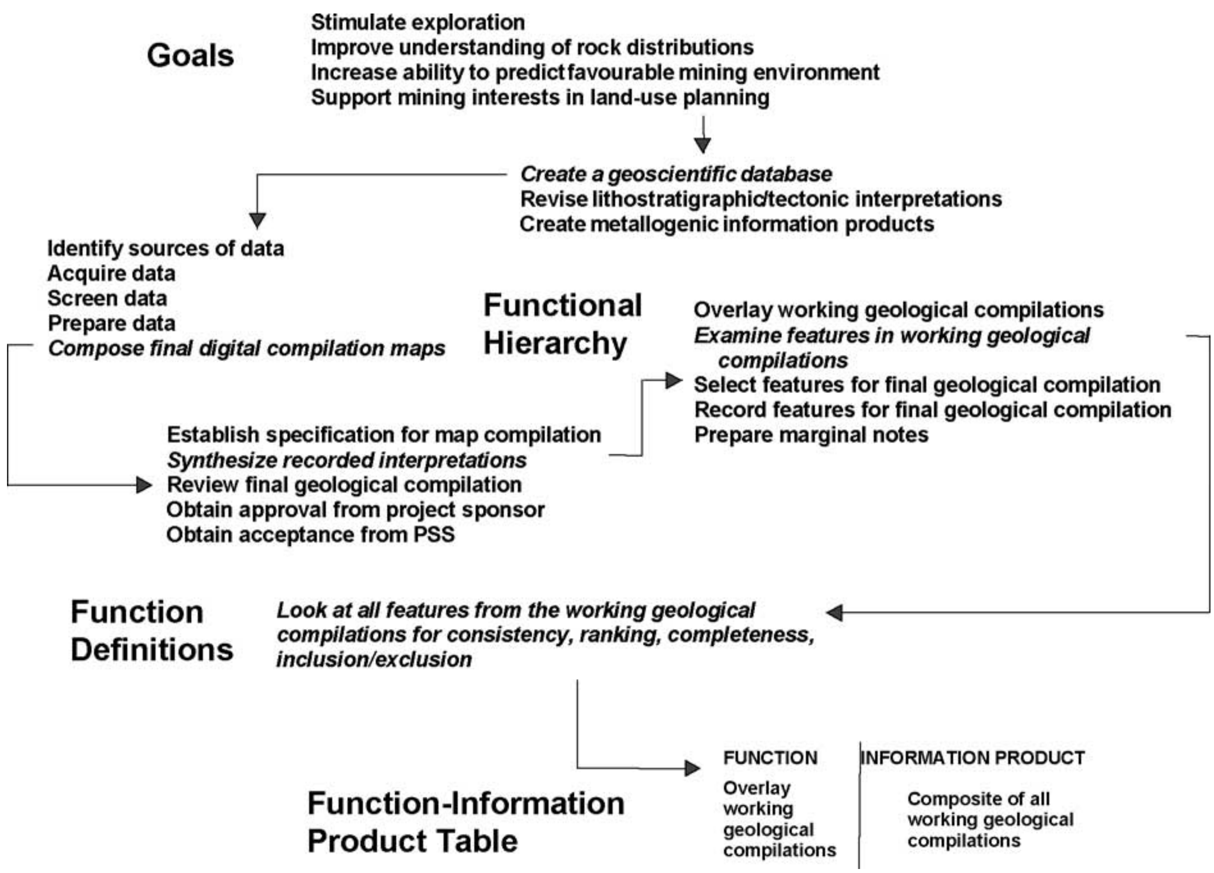

Figure 1. Functional Hierarchy.

(3) managers and supervisory staff who need to keep themselves informed of the progress of the project; and (4) people outside the organization who have an interest, e.g. clients and partners.

The core team meets regularly. In the meetings, the team analyzes and discusses the characteristics of business processes; documents and edits records of discussion (i.e. the Business Functional Hierarchy and the Function Definitions); as well as identifies information products and data sources (which results in the documentation of the Function-Information Product Table and the Information Product-Data Table). At certain milestones, documents resulting from the core team meetings were sent out to other interested parties for comment. The core team is responsible for the review and consolidation of these comments and suggestions into the original JAD documentation.

The JAD methodology is a very effective way of performing business functional analysis. Since it is based on face-to-face and group meetings, it provides a working environment for open communication. It also provides a structure for consensus building by focusing on issues and resolving them. Participation in the meetings is a very useful educational experience for existing and potential users of the data to be delivered. Finally, as the deliverables of the core team are well documented, it provides a solid foundation for data modeling in database design. An example of the Abitibi Functional Analysis is provided in Appendix 1.

FUNCTIONAL EVALUATION OF GIS SYSTEMS

In response to the Ministry's information technology (IT) initiatives and the need for improved capture, analysis and dissemination of geological data, the OGS evaluated three GIS software packages. Under the supervision of senior management, OGS GIS Geoscientists developed evaluation criteria and bench marked the software. The GIS Geoscientists were mandated to propose a GIS solution for the OGS within the IT framework of the Ministry of Northern Development and Mines as well as the broader public sector.

Table 1. Function/Information Products Table. (Note: Table reduced in size in the interests of brevity)

Function #	Function	Information Products
1.1.1	Perform publications search	list of publications
1.1.2	Search unpublished materials	list of unpublished materials
1.1.3	Communicate with peers	notes
1.1.4	Document personal experience	notes
1.2.1.1	Confirm characteristics of data	list of data characteristics
1.2.1.2	Prepare order	purchasing order
1.2.2.1	Perform background check	list of maps and reports
1.2.2.2	Identify critical geologic sites	list of sites
1.2.2.4.2	Make field notes	notes and sketches
1.2.2.4.3	Collect samples	list of samples with description
1.2.2.5.2	Submit samples for analysis	Geochemical Analysis Request
1.3.1	Prepare project checklist	Data Screening Checklist
1.3.3	Check data against checklist	Populated checklist
1.4.1.2	Select appropriate features	list of features
1.4.1.3	Merge individual map sheets/tiles to form seamless map base	seamless map base
1.4.1.4	Weed map base	weeded digital map base
1.4.2.1.1	Specify technique	list of techniques used to re-format data
1.4.2.1.2	Specify media	list of media used to re-format data
1.4.2.1.3	Convert data sets to working formats/media	data sets in working format/media
1.4.2.2	Identify features of interest	list of features of interest

Table 2. Example of Information-Product Data Table. (Note: Table reduced in size in the interests of brevity)

Feature	Type	Classification	Symbol
outcrop areas			
outcrop points			
interpreted areas			
non-interpreted areas			
lake area			
river area			
river line			

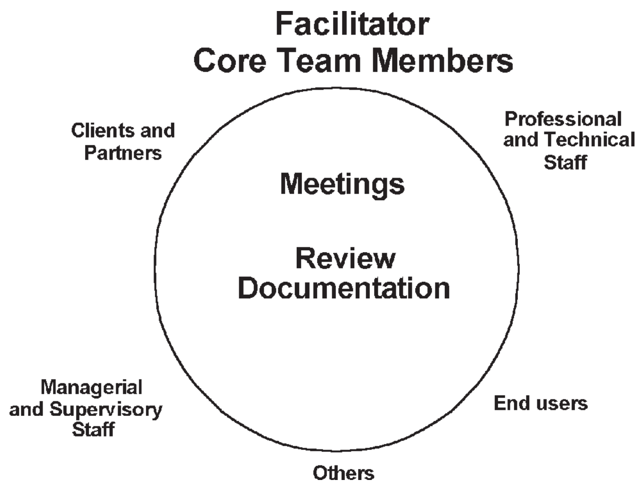

Figure 2. Joint Application Design.

Methodology

In consultation with the Ministry's Data Services Section, four key objectives were defined and are listed below:

- Measure how well the software satisfies current geological analysis requirements,
- Determine what existing systems could be replaced,
- Determine what new analytical features the system could provide,
- Test how well it fits into our existing environment.

The following approach was developed to ensure that the GIS system meets these objectives:

1. Organize the evaluation criteria by the major functions and the critical success factors the system must support. The following high level functions were defined:

    - Data capture and recording of interpretations, e.g., recording geological field observations
    - Data import, e.g., bringing in satellite images or CAD drawings
    - Geological analysis, e.g., creating topologically correct rock unit polygons
    - Data Modeling, e.g., statistical applications
    - Data output and export, such as plotting on a specific plotter, and exporting to Microstation
    - Works within our current and future technical standards

    The following "soft" evaluation criteria were also considered:

    - Compatibility with other organizations
    - Government standards
    - Support, including third party support
    - Training availability, including Community College and University training
    - Is the data structure published?
    - The company's market share, and corporate stability

2. Pre-define the specific sub-processes or data formats that must be supported for each function above. Then define the things you want to measure subjectively and give them priority weighting. For example, under output data, 'it must output a format usable by Publication Services Section' and 'it should be easy to import into Intergraph' (with a weight of 8 out of 10).

3. Establish a test and score the applications' ability to address each of these items listed. The degree of rigor of the test normally depends on how important each item is and how much time is available. Existing systems could be measured against these same criteria to determine whether they could/should be replaced by this new system.

    An example of the Evaluation Form is provided in Figure 3. Those interested in a complete copy may contact the authors for the form in a Microsoft Excel format. For each function there is a minimum required score. Raster capabilities were considered less important for our applications than vector, and consequently they contribute less to the overall score.

4. In addition to doing an evaluation of how well each product meets known needs, it was also agreed that ample time would be allowed to investigate features that the tool provides beyond the immediate known needs. For example, one vendor demonstrated use of the Internet in providing GIS services, a useful capability which we did not have on our list of known needs.

    Most of the selection criteria came from the GIS Geoscientists' experience in mapping, but the following references: Bonham-Carter (1994), Eastman (1995), and Yeung (1995) quite strongly influenced GIS concepts and their application in geology. Martin (1990) also discusses critical success factor analysis, which was also used in the decision making.

Evaluation Criteria

0 - Fail **1 - Poor** **2 - OK** **3 - Good** **4 - Excellent**

	Weight	GIS S/W Score
1. Data Capture and Recording Interpretation		
1.1. Pen Systems (demonstrate the GIS S/W pen-based system)		
1.2. Fieldlog 3.0 (discuss how GIS S/W will incorporate this into its GIS module)		
1.3. From a digitizing tablet	2	
1.4. CAD functionality (points, lines, polygons, levels, line styles, weights. color tables)	2	
1.5. Entering attributes linked to above vector data	2	
1.6. Maintaining and expanding existing OGS symbols library		
1.7. On-screen text editing within GIS S/W (any limitations with respect to size of text block?)	1	
1.8. On-screen digitizing (selective vectorization of raster images)	1	
1.9. Rasterization of vector data		
Subtotal:	**8**	**0**
2. Data Import		
2.1. Vector data		
2.1.1. DWG/DXF		
2.1.1.1. does it import both binary and ASCII DXF files?	2	
2.1.1.2. does it bring across any attribute data stored in DXF file?	2	
2.1.1.3. does it retain layer/color/style/weight parameters of original DXF entities	2	
2.1.2. SHX		
2.1.3. DGN		
2.1.3.1. does it store the DGN MSLINK number and associated attribute data?	2	
2.1.3.3. does it retain level/color/style/weight parameters of original DGN entities	2	
2.1.3.4. does it retain entity type (i.e. point, line, linestring, shape, text, cell, etc.)?	2	
2.1.4. E00		
2.1.4.1. does it bring across attribute data as well as graphical data?	2	
2.1.4.2. does it retain links to all attributes?	2	
2.1.4.3. does it retain topology	2	
2.1.5. MapInfo	2	
2.1.6. Pen Systems Fieldnotes GRD files	1	
2.1.7. Genamap	1	
2.2. Raster data		

Figure 3. Example of Evaluation Form

Performing the Evaluations

Representatives of three GIS vendors visited our site in the fall of 1996 and winter of 1997 to help us evaluate their products. Two days were allotted for each evaluation. All vendors received our evaluation procedure, and for those who wanted it, our test data ahead of time. The first morning of each evaluation, the vendors did a promotional demonstration of their products' capabilities. A typical demonstration was attended by ten or twelve geologists, as well as by the GIS Geoscientists. Over the next day and a half, each vendor team performed the operations on our data as requested in the evaluation procedure.

There was a period of follow-up for several weeks after each evaluation. For example, vendors sent us plot files and export files, which they did not have the time to create at our site. They also provided the necessary information to complete our "soft" evaluation criteria (e.g. support, training, and a list of organizations that use the specific software).

The products showed strengths and weaknesses in different areas of our evaluation, but tabulating the scoring of the functional evaluation criteria indicated which products would best suit us.

We also considered the previously discussed "soft" factors. We wanted to be compatible with as many of our geological colleagues as possible and therefore considered the software being used by the Geological Survey of Canada as well as neighboring provincial and state geological surveys. Finally, we considered Ontario government software standards and the software used by the Ontario Ministry of Natural Resources, our source for digital topographic data as well as the Ontario government's lead ministry in GIS Information Technology.

Results

As a result of the evaluations we selected ESRI Arc/Info and ArcView products as the workstation and desktop GIS staples for the Ontario Geological Survey. This combination of products offers the best solution to our current needs as well as our requirements in the near future. This solution offers a minimum impact on our current cartographic processes thus allowing us the ability to continue to generate hardcopy cartographic products utilizing a methodology that we have developed with time, while allowing us the ability to migrate to a new delivery system in a functional fashion.

COMPILATION AND PRODUCTION

Compilation

The process of compilation that was used came directly from the Functional Analysis (Appendix 1). The Data Screening Checklist (Table 3), also a product of the functional analysis, clearly lays out the data sets we had to

Table 3. Example of a Data Screening Checklist. (Note: Table reduced in size in the interests of brevity)

Data	Source	Scale	Projection	Datum	DTM's
AFRI					
Airborne Magnetics					
Airborne Electromagnetics					
Drill Hole Database					
External Geological Information					
Field Observations					
Gamma Ray Spectrometry					
Geochronology					
Geology: 250000 seamless base					
Geology: 2000 series					
Geology: P-maps					
Gravity					
Lake Sediment Geochemistry					
Landsat TM					
Lithogeochemical Database/LIMS					
Mineral Deposit Inventory					
NTS					
OBM (DTDB)					
Quaternary Geology					
1:50 000 series					
Radar Data					
Till Geochemistry					

work with and what features were pertinent to the compilation process. For our purposes, we subdivided the data into two sets - Map Data and Tabular Data.

Map Data include both vector and raster data sets including the following themes:

- Topographic Map Data
- Geological Map Data
- Geophysical Map Data (aeromagnetic grids and electromagnetic anomalies)
- Remote Sensing Map Data (Landsat TM and Radarsat)

Tabular data consisted of the following databases:

- Lithogeochemistry (ERLIS – LGC)
- Assessment File Research Inventory (ERLIS – AFRI)
- Ontario Drill Hole Database (ERLIS – ODHDB)
- Mineral Deposit Inventory Database (ERLIS – MDI2)

Production

Implementing the use of the new GIS software solution was not immediate. The OGS continued to use their existing software applications such as MapInfo, AutoCAD and Microstation while the skills for Arc/Info and Arcview were developed. By the time the second of four sheets had begun, these skills were sufficient that a considerable amount of the work was done solely in Arc/Info and Arcview. This has facilitated the release of the GIS product yet has had minimum impact on the established cartographic process, a process that continues to produce full coloured hard copy maps for which no GIS product is required. Eventually, with experience gained from our newly implemented tools, all hard copy maps will have a corresponding digital GIS product.

CONCLUSIONS

The outcome of this project is a scientific document; i.e. a geological map. The procedures we followed however, in going from an analogue world of paper maps at the beginning to a digital, attributed map at the end really involved a major paradigm shift in the way "business" or map production at the Ontario Geological Survey occurs. This paper was written to capture the process by which this change occurred. It is neither meant to be a template for describing how such changes should take place nor is it held up to be necessarily the correct way to effect such changes.

ACKNOWLEDGMENTS

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NOTE: As stated throughout, numerous tables and figures have been reduced in size and breadth in the interests of brevity. Should you require comprehensive documentation, tables will be provided in MS-Excel and MS-Word by simply contacting one of the authors.

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APPENDIX 1. ABITIBI FUNCTIONAL ANALYSIS

Abitibi Compilation - Project Documentation

(Note: the content of the following has been greatly reduced in the interests of brevity. Should you require additional detail, please contact one of the authors at the Ontario Geological Survey)

A. GENERAL INFORMATION

1. Business Activities
2. Goals
3. Objectives and Scope
4. Usefulness
5. Clients
6. Custodians
7. Sponsor

B. FUNCTIONAL HIERARCHY

8. CREATE A GEOSCIENTIFIC DATABASE

8.1 Identify sources of data
8.2 Acquire data
8.3 Screen data
8.4 Prepare data
8.5 Compose final digital compilation maps

9. REVISE LITHOSTRATIGRAPHIC/TECTONIC INTERPRETATIONS

9.1 Identify new business needs
9.2 Modify project objectives/specifications as needed
9.3 Identify stratigraphies and tectonic environments in existing interpretations
9.4 Create working lithostratigraphic interpretation from geological compilation
9.5 Produce digital information products
9.6 Refine contents of working lithostratigraphic interpretation

10. CREATE METALLOGENIC INFORMATION PRODUCTS

(The analysis of this function is in progress. Function definitions and tables to be completed)

10.1 Identify new business needs
10.2 Modify project objectives/specifications as needed
10.3 Use computer-assisted technologies
10.4 Produce information products

Integration of Relational Geologic Databases and a Spatial Map Database in Kentucky

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The Kentucky Geological Survey's primary geologic mapping database will be connected to the KGS comprehensive geologic/hydrologic relational database. This comprehensive database (Fig. 1) has evolved considerably during the 20 years KGS has been computerizing data. Currently it contains data from more than 200,000 geographic locations throughout the Commonwealth. These data consist of well locations (petroleum and water), well construction information, coal-thickness measurements, sample descriptions, analyses (coal, water, petroleum), and descriptive information. Plans for the near future are to install a spatial data engine (SDE) that will provide the capability to store spatial information in the relational database. In addition, plans are to link images derived from scanning official paper documents (for example, plats, drillers logs, well tickets, down-hole logs) to their respective computerized records in the database. This will provide users with immediate access to copies of the original records as received by KGS.

Retrieving and manipulating data from the main relational database is accomplished by client applications using ODBC (open data base connectivity) drivers, SQL (structured query language) code, or programming languages such as Visual Basic (VB) or C++.

Geologic map information is collected as vector data by a GIS and stored in the KGS digital geologic mapping database. These spatial data consists of numerous coverages such as formations, structures, faults, coals, minerals, fossils, drill holes, and dikes. Each coverage or layer consists of polygons, arcs, or points, and has attribute tables that describe the coverage. The formation code (FMCODE) and geologic quadrangle map name (GQNUM) are primary attribute headings and serve to link other descriptive tables such as type, name, and style. These attribute tables are the basic components of the mapping database, and are directly related by scripts or hot links to additional digital mapping subdatabases containing information on subjects such as metadata, lithology, stratigraphy, mineral veins, and fossils (Fig. 2).

The Stratigraphic table and code of the spatial database is very important in that it is a primary table that will link the data captured in the KGS spatial mapping database with the U.S.Geological Survey (USGS) draft data model (Fig. 3).

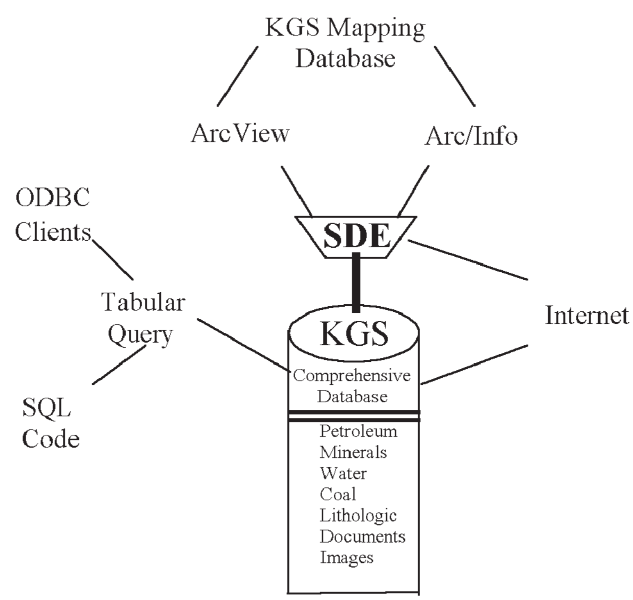

Figure 1. Organizational Structure and access points for the KGS Comprehensive and GIS Mapping Databases.

Coverages (.aat, .pat, .pat)	Attribute Tables (10 character name)
Formation Arcs	Type, Name, Fmcode, GQnum, Style
Example	*Contact, Qal, 111ALVM, 123, contact*
Formation Polys	Name, Fmcode, GQnum
Structure Arcs	Type, Name, Desc, Value, GQnum
Structure Points	Type, Desc, GQnum, Heading, Dipdir, Az*, Dip, Source
Fault Arcs	Type, Name, Desc, GQnum, Throw, Style
Example	*Fault, Pine Mountain, Thrust, 123, DTE,*
Coal Arcs	Type, Name, Fmcode, GQnum, Style
Example	*Coal, FC, 324Ambg, 134,*
Coal Points	Type, Name, Fmcode, GQnum
Mineral Arcs	Type, Name, Desc, GQnum
Example	*Mineral, Vein, Barite, 628*
Mineral Points	Type, Name, Desc, Activity GQnum
Drill Holes	Type, Name, ID, GQnum
Dike Arcs	Type, Name, Desc, GQnum
Fossil Arcs	Type, Name, Desc, GQnum
Example	*Fossil, G, USGS 5024-CO, 628*
Fossil Points	Type, Name, Desc, GQNum
Miscellaneous Arcs	Type, Name, Desc, GQNum
Miscellaneous Points	Type, Name, Desc, GQNum

Accessory Databases and Look up tables include: Metadata, Stratigraphy, Lithology, Paleontology, Minerals

Figure 2. Components of Kentucky Geological Survey Spatial Database for Geologic Map Information.

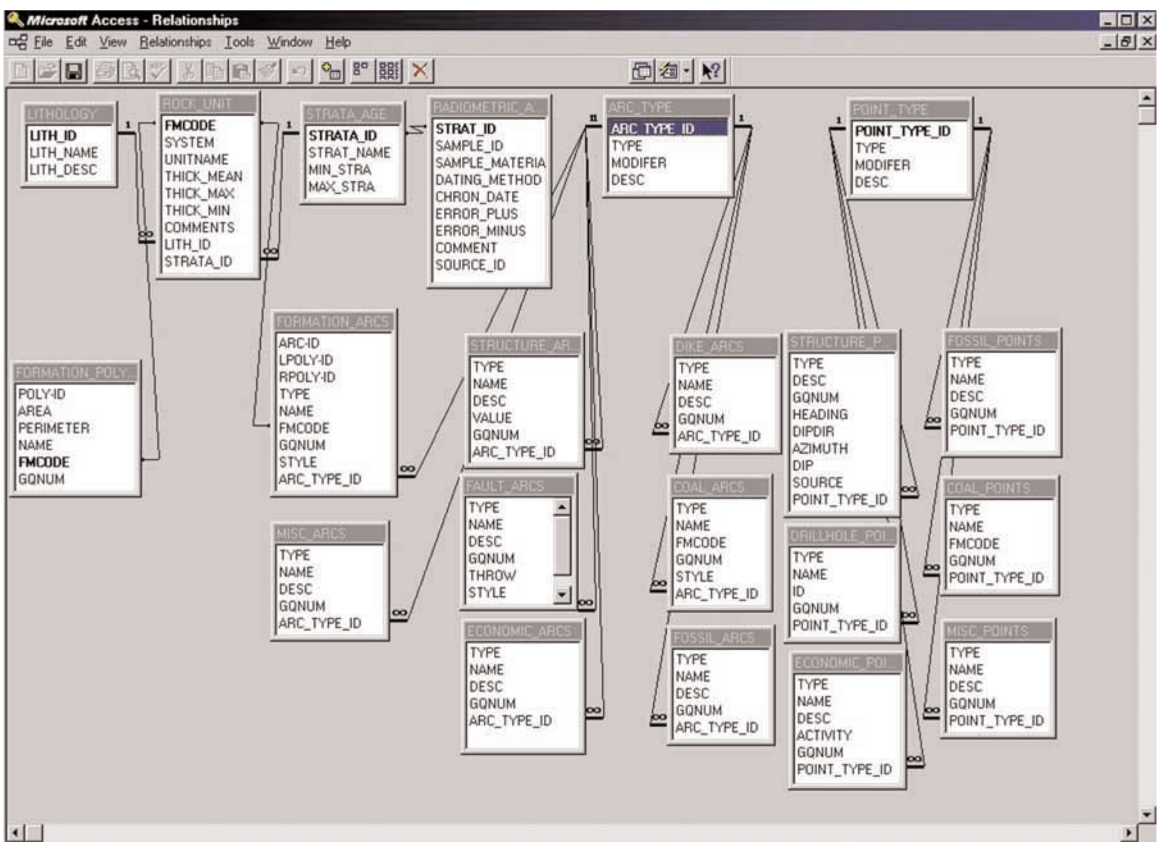

Figure 3. The relationships between the KGS Digital Geologic Mapping Database Structure (formation, structure, faults, dikes and coal arcs and polygons) and three primary components of the USGS draft data model (lithology, rock unit, and strata age). These three tables serve as the primary link to access auxiliary tables in the KGS spatial and relational databases.

Other subdatabases are designed to meet various needs; for example, the metadata files use a State-suggested software for metadata compilation. The lithology database is created to supplement the digital mapping files, and the fossil database is linked to a USGS fossil identification number and description.

A GIS can be used to perform spatial queries, to locate oil-or water- well information and coal-bed thickness or mineral data; and these data are linked to other geologic, engineering, and mineral databases for resource manipulations, searches and modeling. Pseudo 3-dimensional models have been created using digital elevation models and 2-dimensional digital geologic maps to give the appearance of a three-dimensional view. This allows planners, developers, miners, and engineers to conduct slope stability studies, approximate cut and fill calculations, and use the GIS analytical tools to manipulate geologic data. Digital elevation models and geologic data have been manipulated to obtain line-of-sight surface profiles and area measurements. Plans for adding z-values will enable volume measurements to be performed.

Currently, the KGS can integrate its spatial mapping data files with the Kentucky Department of Transportation's (DOT) engineering database so that rockfall and landslide parameters can be merged into our digital geologic mapping files. DOT is currently evaluating these data to determine how they can be used to increase the efficiency of highway planning and maintenance. These geologic map files have also been used as a base to integrate other nongeologic coverages such as environmental wetlands, parcel mapping, cultural, and best cost estimates for planning highway corridors.

Customized scripts have been created to develop a template for automatic formatting of hard-copy output of digital map data. These scripts will enable a user to specify the name of the quadrangle, author, and date; modify a generic legend and stratigraphic information so that a draft quality quadrangle map can be plotted (Fig. 4). This draft map does not have a geologic column or cross section, but we are working on methods to create these two components.

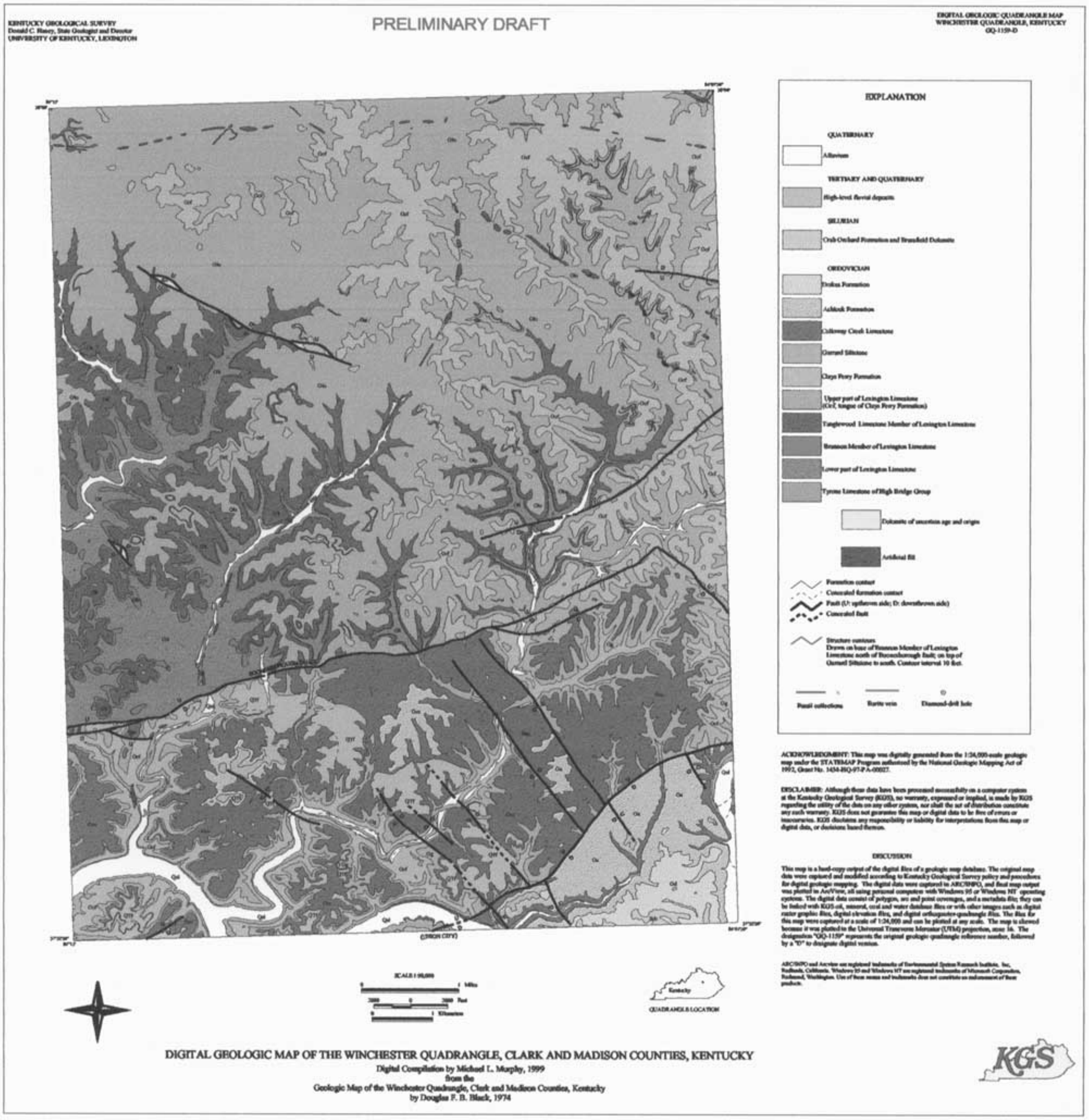

Figure 4. Preliminary draft of a geologic map using an Avenue script to create a template for rapid plotting of different geologic maps.

Geologic Mapping and Collection of Geologic Structure Data with a GPS Receiver and a Personal Digital Assistance (PDA) Computer

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INTRODUCTION

Recent advances in handheld and Personal Digital Assistance (PDA) computers have revolutionized the way people work, communicate, and store and collect data. That revolution is making its way into the business of making geologic maps. During the summer 1998 field season, the U.S. Geological Survey (USGS) utilized PDA computers in conjunction with Global Positioning System (GPS) receivers to conduct 1:24,000-scale bedrock geologic mapping in southern and central New Hampshire. The effort was considered experimental at first, but we rapidly learned that the combined use of a PDA computer and GPS receiver was an efficient way to collect geologic field data.

Field data collection systems have been employed in geologic mapping for several years. Brodaric (1997) described a comprehensive software package called Fieldlog, developed and used by the Geological Survey of Canada. Fieldlog utilizes an Apple Newton Message Pad computer running Fieldworker data collection software. Unfortunately for users of this hardware and software, and for those in the stages of planning an upcoming field season, Apple discontinued the production and support of the Newton in the spring of 1998 so we turned to the burgeoning market of PDA computers. Here we describe the results of our field use of a PDA computer and a GPS receiver for the collection of geologic structure data.

The primary goal of utilizing a GPS receiver and a field data collection system was to address the problem of digitally compiling, in a time efficient manner, numerous geologic structure measurements taken during the course of mapping. The compilation of structure data is often the most time-consuming process in the production of digital geologic maps, especially in areas underlain by complexly deformed and metamorphosed rocks with multiple histories of ductile and brittle deformation. In order to eliminate the need to either spend additional field time entering data on a laptop computer or performing heads-up digitization of drafted and scanned structure symbols in the office, we decided to collect structure data real-time in the field. In order to achieve this goal we needed a highly portable system that would allow, rapid collection of geologic attribute data and positional point data. A secondary goal was to use a data collection system that used popular hardware and software, making it easy for field geologists to learn and customize it to meet their needs.

HARDWARE AND SOFTWARE

The data collection of point attributes for geologic structures was designed around the need to create an

Arc/Info point coverage of structural geology. Although untested, the system would probably work well with other GIS packages. The PDA computer of choice was the 3Com Palm III running Pendragon Forms data collection software version 1.2. Pendragon Forms is a form-based software package that can utilize the database functionality of Microsoft Access in Windows 95, 98 or NT. Data collection forms that include lookup or pulldown lists and numeric key pads can be created in Pendragon Forms, Microsoft Excel, or any ASCII text editor and then transferred to the Palm Pilot. This allows users the flexibility to use the software or the particular data fields that they prefer and are most familiar with. Positional data was collected with Rockwell PLGR+96 GPS receivers using the Precise Positioning Service (PPS) available to workers in the U.S. Federal government. The use of the PPS allowed collection of GPS data with a real-time advertised accuracy of less than 20 meters, and an experienced accuracy of generally less than 5 meters. This accuracy enabled mapping at 1:24,000 without the need for post-processing the GPS data. The data collection system we employed would still work with GPS data collected under Selective Availability (SA), but would require the additional steps necessary for post-processing the data if mapping was conducted at 1:24,000 or larger scales. Waypoints recorded at outcrops where structure data were gathered were electronically transferred, or dumped, from the PLGR+96 to a laptop computer in ASCII format using Microsoft Hyperterminal.

PROCEDURES

The initial phase of developing a data collection system on the Palm III involved creating a form in Pendragon Forms. The data collection form was designed for geologic structure data that would be compatible with an Arc/Info point attribute table, or PAT. The items in the PAT, according to the data model we developed for mapping in New England's complexly deformed rocks, are shown in Table 1. This data model is generally compatible with the Structural Detail Table in the proposed digital geologic map data model of Johnson and others (1998), but contains more items pertaining to GPS positions and detailed structural analysis in complexly deformed rocks. In creating the data collection system in Pendragon Forms, the user has options to generate lookup lists, numeric keypads, popup lists, and many other types of common data entry forms. These forms, lists, and keypads allow the user to minimize the amount of handwriting or typing, and thus expedite data entry. Figure 1 shows a partial example of the lookup list for the geologic structure item SUB_TYPE. Because the forms are so easy to create, the available options in the lookup lists can be modified to fit any particular data model.

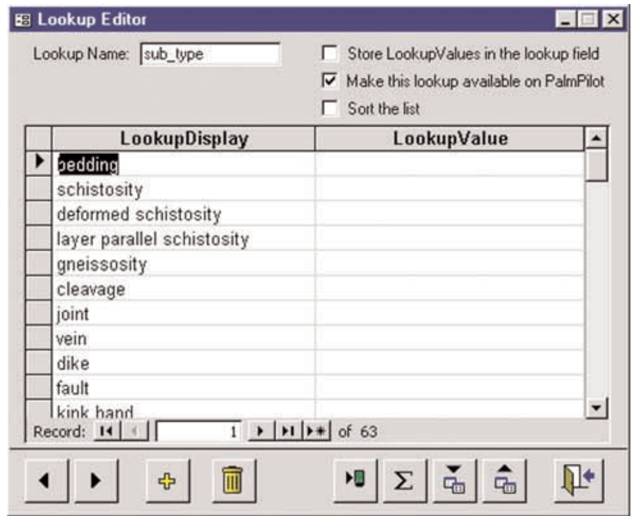

Figure 1. Partial example of a lookup list for the geologic structure item SUB_TYPE. The SUB_TYPE lookup list includes valid data entry values for planar data such as bedding and schistosity shown above, linear data such as fold axes and intersection lineations, and other data such as mines and quarries to name a few.

Once the forms are complete and they match your data model, you can collect your attribute data and positional waypoint data in the field at every outcrop with the PDA computer and the GPS receiver. The PDA and the GPS need not be physically connected in the field, unlike many data loggers that come as accessories to GPS receivers. This is significant, as it eliminated the need for a connecting wire between the PDA and the GPS, and allowed greater freedom of movement through rugged terrain and dense undergrowth.

After data collection, the PDA and the GPS data are downloaded to a desktop or laptop computer running Microsoft Access and Microsoft Hyperterminal, respectively. Downloads could be completed as often as every day, or as infrequently as once a week depending on access to a computer. We found that access to a laptop in the field office was the most reliable way to ensure adequate backups of the data. Data from the Palm III downloads directly into a Microsoft Access database file, whereas data from the PLGR downloads to an ASCII text file. Positional data from the GPS receiver represent a single point and the attribute data may represent one or many geologic measurements at that point. The attribute data in Access and the positional data in ASCII format are then combined into a single database by establishing a one-to-many relationship in Access using the station and waypoint label as the relate item. After field work is completed, or at any time when a compilation map is desired, the Microsoft Access data can be converted into an Arc/Info point coverage.

The first step in creating the Arc/Info point coverage is to create two separate files from the Access database: 1) an ASCII text file of positional data, and 2) a DBASE IV file of attribute data. This is accomplished by running two select queries in Access and then exporting the two resulting tables to new ASCII and DBASE IV files. In our procedure we name the ASCII file *coor.txt* and the DBASE IV file *attr.dbf*. In New Hampshire, we collected GPS data in UTM coordinates so our coordinate file (*coor.txt*) has three comma-delimited fields: station, east, north. Before exporting, ensure that both files, or select query tables, have the same number of lines and have been sorted by the station field in ascending order. Next add the word "end" as the last line of the coordinate select query table and export the file; the resulting *coor.txt* file should look like this:

```
4001,308764,4743207        — first line
4001,308764,4743207
4002,308649,4743384
4002,308649,4743384
...
…
…
6534,312728,4737407
6534,312728,4737407
6534,312750,4737419
end                        — last line
```

The format (field size or width and data type, such as numeric or text) of the *attr.dbf* fields does not have to be explicitly defined in Access or in DBASE because it will be defined when the DBASE file is converted to an INFO file in Arc/Info.

The generalized procedures for collecting and transferring data to an Arc/Info point coverage are outlined in Figure 2. The generation of the point coverage can be automated by running an Arc/Info macro or AML. The AML (*convertdbf.aml*) uses the Arc/Info commands DBASEINFO, GENERATE, BUILD, and JOINITEM and is illustrated below:

```
/**********************************
/* Name: convertdbf.aml
/* Purpose: Converts Palm III PDA and PLGR
/* GPS Access data into an ARC point cover
/* Requires the following files:
/*      attr.dbf    {DBASE IV format}
/*      coor.txt    {ASCII format}
/* Usage: &r convertdbf <outcover>
```

Table 1. Items used in the data collection system and the Arc/Info point attribute table (PAT). The description refers to the positional or geologic nature of the item. The source refers to the source of the data either from the GPS waypoint or the Palm III data entry form.

ITEM:	DESCRIPTION:	SOURCE:
STATION	station identifier	numeric keypad
POSFMT	GPS position format	waypoint
ZONE	GPS utm zone	waypoint
HDATUM	GPS horizontal datum	waypoint
HRZERR	GPS horizontal error	waypoint
ELEV	GPS elevation	waypoint
VDATUM	GPS vertical datum	waypoint
ELEVUNIT	GPS elevation units	waypoint
TYPE	geol. structure (planar, linear, other)	lookup list
SUB_TYPE	geol. structure (joint, bedding, etc.)	lookup list
STRIKE	geol. structure (0-359 in right-hand rule)	numeric keypad
DIP	geol. structure (0-90)	numeric keypad
DIPDIR	geol. structure (0-359 in right-hand rule)	numeric keypad
REL_AGE	relative age of geol. structure	lookup list
SYMBOL	symbol number from Arc/Info markerset	numeric keypad
SYMBOL_ANG	Arc/Info symbol rotation value	calculated in Arc/Info
ROTATION	relative rotation of geol. structure	lookup list
SPACING	spacing of joint sets or fracture zones	numeric keypad
WIDTH	width of joint sets or fracture zones	numeric keypad
NETSLIP	net slip of small-scale fault	numeric keypad
APERTURE	aperture of joints or fractures	numeric keypad
MIN1	primary mineral in vein or fracture	lookup list
MIN2	secondary mineral in vein or fracture	lookup list
MIN3	tertiary mineral in vein or fracture	lookup list
CODE	relate item to geologic polygons	freehand text

```
/* Project: USGS New Hampshire
/* Date: September, 1998
/* Authors: Jim Reddy and Greg Walsh
/*
/*************************************
&args cover
/*    OPEN TABLES - CHECK FOR
/*   EXISTING ATTR.DBF DATA TABLE
tables info
&if [exists attr -info] &then kill attr
quit

/*    CONVERT THE ATTR.DBF FILE
/*    TO AN INFO DATA TABLE
/*     Modify the following definitions to match
/*    your ATTR.DBF file and your data model
dbaseinfo attr.dbf attr define
station station 6 6 n 1
posfmt posfmt 8 8 c
zone zone 4 4 c
hdatum hdatum 8 8 c
hrzerr hrzerr 4 4 i
elev elev 5 5 i
vdatum vdatum 8 8 c
elevunit elevunit 2 2 c
type type 10 10 c
sub_type sub_type 35 35 c
strike strike 3 3 i
dip dip 2 2 i
dipdir dipdir 3 3 i
rel_age rel_age 10 10 c
symbol symbol 3 3 i
symbol_ang symbol_ang 3 3 i
rotation rotation 3 3 c
spacing spacing 5 5 c
width width 5 5 c
netslip netslip 5 5 c
aperture aperture 5 5 c
min1 min1 3 3 c
min2 min2 3 3 c
min3 min3 3 3 c
code code 8 8 c
end

/*   GENERATE THE POINT COVERAGE
/*   FROM THE COOR.TXT INPUT FILE
&if [exists %cover% -cover] &then kill %cover% all
generate %cover%
input coor.txt
points
quit

/*   BUILD THE POINT COVERAGE
build %cover% point
```

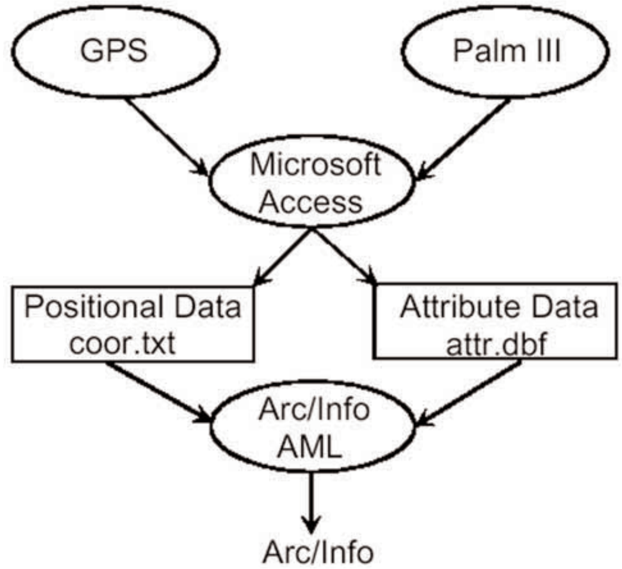

Figure 2. Flow chart showing the generalized procedures for collecting and transferring data to an Arc/Info point coverage.

```
/*   JOIN THE POINT COVERAGE PAT FILE
/*   AND THE ATTR DATA TABLE
joinitem %cover%.pat attr %cover%.pat %cover%#
%cover%-id link

&return
```

Once the point coverage is created, SYMBOL values can be checked or added based on values from marker symbols in an Arc/Info markerset of geologic symbols such as those created by Fitzgibbon and Wentworth (1991). Before plotting the symbols in the correct orientation, the item SYMBOL_ANG must first be calculated from STRIKE values for planar symbols and DIPDIR values for linear symbols. This calculation depends largely on the orientation of the symbols in the markerset and the method of collecting strike data. After calculation of the item SYMBOL_ANG, the pseudo item $ANGLE can be calculated as equal to SYMBOL_ANG. The pseudo item $ANGLE records the rotational angle for individual symbols in Arc/Info and is based on a Cartesian coordinate system with East = 0°, North = 90°, West = 180°, and South = 270°. This differs from standard geologic angles where North = 0°, East = 90°, South = 180°, and West = 270°.

RESULTS

At the time of this report, mapping in two 7.5-minute quadrangles (Windham and Pinardville) in southern New

Hampshire and the Hubbard Brook watershed in central New Hampshire has successfully employed this field data collection method. In the case of the Windham quadrangle, mapping was completed in September 1998 and a complete digital geologic map with over 2400 structure symbols was compiled and submitted for review by February 1999 (Walsh and Clark, 1999). Digital compilation of the Pinardville quadrangle is almost complete and additional geologic mapping in the Hubbard Brook watershed is scheduled for the 1999 field season.

In the past, data collection typically involved recording structure data in field notebooks by hand followed by data entry into a computer database or heads-up digitizing of drafted and scanned structure symbols after the completion of field work. The old method often led to lengthy periods of data processing and even simplification of the dataset in order to meet budgetary constraints and deadlines. The Hartland quadrangle in Vermont is underlain by similarly complex geology and the Arc/Info point coverage contains 1600 points (Walsh, 1998). Compilation of the structural geology point coverage took a total of approximately 40 hours and included hand-drafting of symbols with pen and ink on mylar (24 hours), scanning and registering the drafted symbols (1 hour), and heads-up digitizing (15 hours). For comparison, compilation of the point coverage for the Windham, New Hampshire quadrangle required only approximately 10 hours and included periodically downloading GPS and Palm III data (8 hours), data manipulation in Microsoft Access (1 hour), and generation of the Arc/Info point coverage (1 hour). In this comparison, the old method used in Vermont took four times as long to create a point coverage with only two-thirds the number of points.

CONCLUSIONS

The USGS developed a field data collection system for geologic mapping that utilizes GPS receivers and PDA computers. The system uses a PLGR+96 GPS receiver with the Precise Position Service and a 3Com Palm III PDA computer running Pendragon Forms data collection software. Data transfer to an Arc/Info point coverage of structural geology is accomplished by data manipulation in Microsoft Access, data extraction to ASCII text and DBASE IV files, and data conversion using an Arc/Info macro (AML). The method has allowed for the rapid, accurate collection of abundant structural geology data in complexly deformed and metamorphosed rocks. This method greatly expedites the digital compilation of geologic map data in a GIS and, although untested in other geologic settings, should be easy to apply to other areas.

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Walsh, G.J., and Clark, S.F., Jr., 1999, Bedrock geologic map of the Windham quadrangle, Rockingham and Hillsborough Counties, New Hampshire: U.S. Geological Survey Open-File Report 99-8, scale 1:24,000.

ArcView, a Geologic Mapping Tool

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INTRODUCTION

This is the second year that geologists at Missouri's Geological Survey Program (MGSP) have used ArcView (version 3.0 in 1998, and version 3.1 in 1999) to produce geologic maps for the STATEMAP project. STATEMAP is a component of the National Cooperative Geologic Mapping Program. Each geologist takes his or her map from the initial entry of field data to the final published product. It has been found that the "heads up" mapping on a USGS Digital Raster Graphic topographic map (DRG) displayed on the monitor has many advantages over conventional pen and ink mapping. Geologists using these techniques can readily create a variety of graphically displayed working hypotheses to improve the accuracy of the interpreted geologic map. The ability to use separate themes to quickly draw, view, modify, and erase interrelated features is especially valuable. Geologists can easily compare common boundaries between their map areas and assure that the interpretations match. This facilitates compilation of 1:24,000 sheets into composites. The techniques used by Missouri's Geological Survey Program have involved the typical trial and error of any new technology. These techniques are rapidly evolving as the geologists become increasingly familiar with the capabilities of the software and each makes contributions from his or her own area of expertise. Some of the experiments of the past two years are discussed in the following paragraphs in anticipation that they might prove useful to geologists mapping in other states.

FROM FIELD DATA TO DIGITAL INFORMATION

MGSP geologists collect field data by drawing outcrops on a 7.5 minute USGS topographic map and identifying each outcrop with a number. ArcView and USGS DRG's have made it possible to easily print sections of the topographic maps on 11x17 inch paper at 1:12,000 for use in the field. This enlarged scale makes it easier to draw and label outcrops legibly on the field maps, especially where there is a high density of outcrops. A field notebook is maintained with a description of each outcrop and general traverse information.

Upon returning to the office, an outcrop map is prepared by copying the marked outcrops from the field map to the DRG by drawing a polygon in ArcView with the mouse (figure 1). The size of small outcrops is exaggerated so that they will be visible while drawing the bedrock contacts. Outcrops are typically entered with the view zoomed in to a scale of 1:4000 or less. Key information including ID number, formation, lithology, and structures are entered into the attribute table. Traverses are separated as to whether they were made by car, boat, or foot and are entered as line themes. Recording traverses on the map documents where the geologist went in the search for outcrops, whether or not any were found. Complete field notes are typed into a text file using Microsoft Wordpad and then copied to individual outcrop or traverse files so they can be displayed in ArcView by merely clicking on the feature with the "hot link" tool. Sketches, annotated

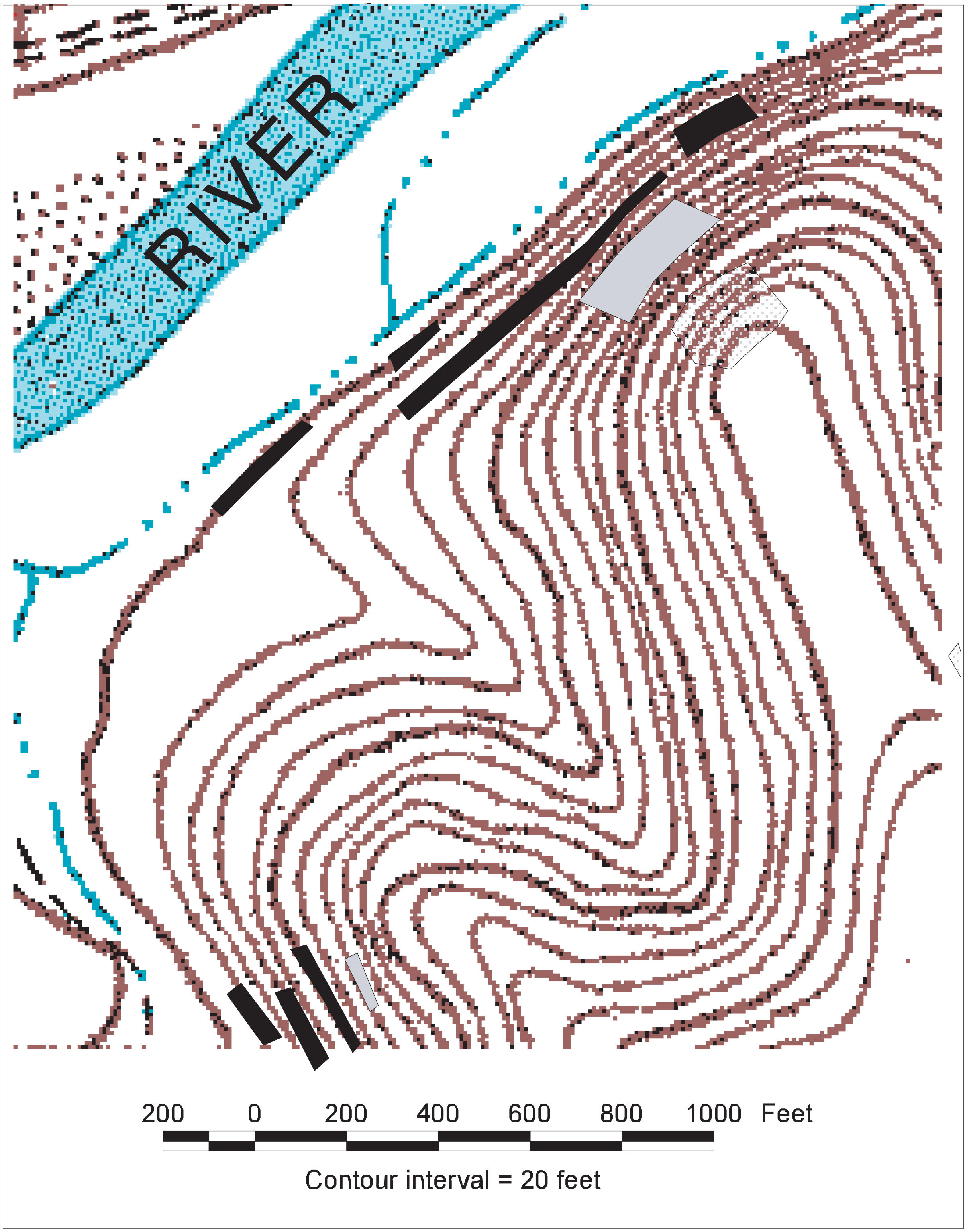

Figure 1. Enlargement of a portion of the Grandin SW 7.5 minute quadrangle showing outcrop polygons for three map units. The four outcrops shown in black, closest to the river are Lower Gasconade Dolomite. The dark gray outcrop in the middle is Upper Gasconade Dolomite and the light gray outcrop at the highest elevation is Roubidoux Formation (the outcrops are normally displayed in easily distinguishable colors). All are of Ordovician age. The outcrop map is the basic map of the field data and is used as the basis for all of the interpreted maps.

photos, and measured sections can be drawn or entered into a separate view and linked to the outcrop to permit retrieval by a click of the mouse. These data and displays are used in preparation of the final interpreted maps and are available for reference by other geologists working in the mapped areas on environmental projects, mineral exploration, etc. The actual format in which these supporting data will be made available to the public has not been determined at this time, but will probably be on a CD.

INTERPRETATION TECHNIQUES

The purpose of the mapping is to produce a bedrock geology map that shows the formation (or other mappable unit) occurring at the surface as well as any mappable structures. The bedrock geology map units are drawn as polygon themes. Structures are drawn as line themes.

Each map unit is drawn as a separate theme starting from the oldest up. The lowest formation is drawn as a polygon with vertices at only the four corners of the map. Each stratigraphically higher unit is drawn to enclose the areas that lie topographically above its basal contact. In this technique, editing is quick and easy. The themes are merged after editing is complete and before distributing or printing the maps.

Mapping is straightforward in areas where outcrops are abundant, control on contact elevation is good, and the strata are close to horizontal. The contacts can be drawn as bedrock geology polygon themes by following the DRG contours and visually interpolating the elevation between the outcrops, which are color coded for each map unit. Faults are drawn as line themes and the bedrock polygons can be closed on either side of faults or carried across the fault with the appropriate offset depending on the mapper's preference.

In areas where outcrops are widely scattered or sparse and the strata are folded, ArcView is a very useful tool for graphically overlaying different data sets and working them against each other to find the best fit map for all the data. Adding themes for structure and isopach contours was very helpful on one quadrangle where mapping was complicated by a combination of broad folds and map units of variable thickness. With the structural and stratigraphic complications and the complex dendritic drainage pattern, it was difficult to simply "eyeball" the elevation of the contacts correctly between the moderate number of outcrops.

One of the contacts was exposed in several outcrops throughout the quadrangle. By preparing a structure contour map (figure 2) on this horizon and overlaying the structure map on the topography, it was easier to interpret the elevation of the contact. The first step in creating the structure map was to visually scan the outcrops for those where a reliable elevation could be picked and enter those outcrops as a separate point theme with the elevations

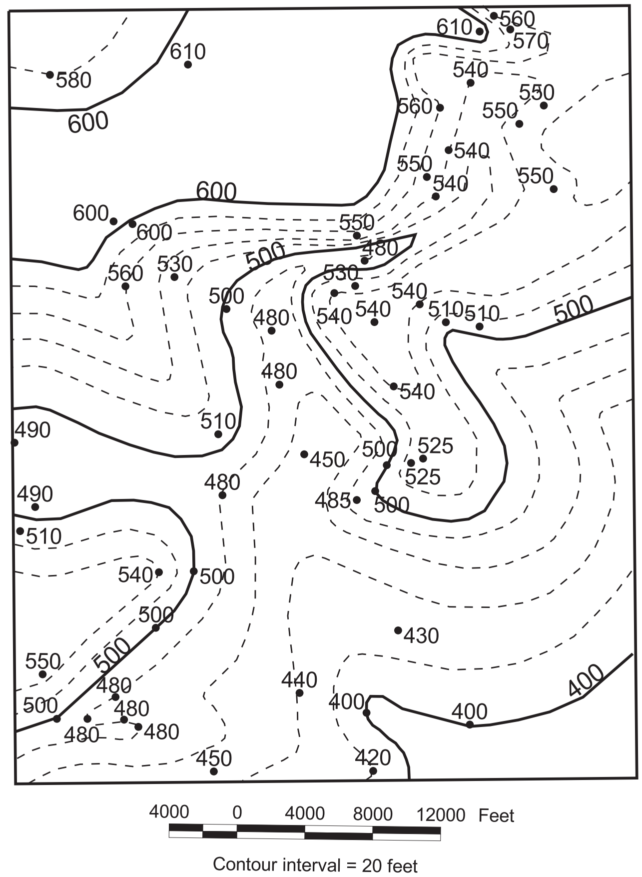

Figure 2. Map of the Grandin SW 7.5 minute quadrangle showing structural control points, and structure contours.

entered in the attribute table. Each point was then labeled with the elevation. A structure contour map was then drawn as a line theme, using these data points as a base.

In order to draw the bedrock geology polygons, the outcrop theme was turned on with each of the outcrops color coded by formation. The structure contour lines were also color coded to facilitate recognition and make mapping easier. The DRG was placed on top and the white and green colors were made transparent. The bedrock polygons were then drawn with the contact at the correct elevation on the DRG by visually interpolating between the structure contours and the outcrops.

A similar approach was used to draw the contact which overlies a map unit of variable thickness. Because of thickness variations, the contact could not simply be drawn a fixed vertical distance higher throughout the map. In this case, there were enough outcrops where a maximum, minimum, or actual formation thickness could be determined. Those outcrops were entered as a separate point theme and labeled. The isopach maps were drawn as a line theme from these data points (figure 3). Isopach contours were labeled but left black. The contact above this unit of variable thickness could then be drawn by visually interpolating between the structure contours, the isopach contours, and the outcrops (figure 4).

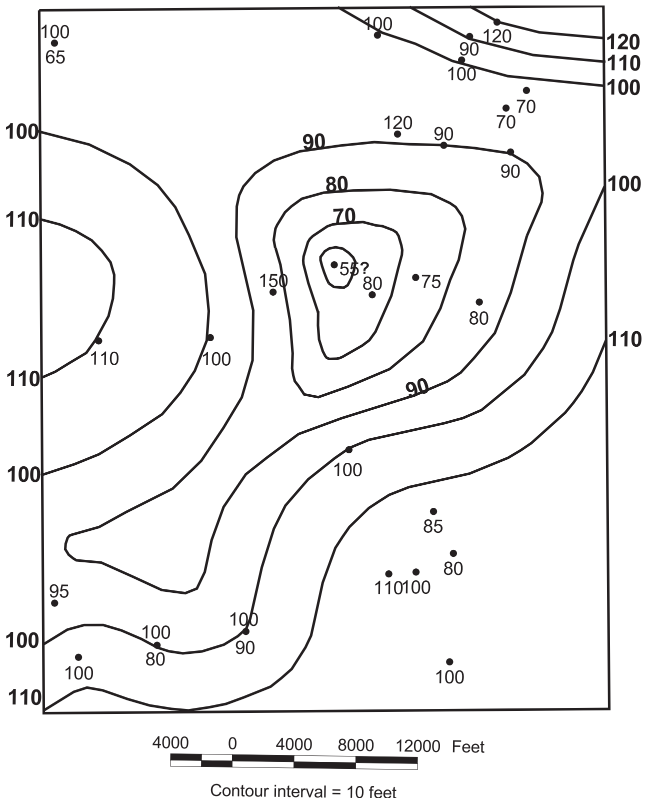

Figure 3. Map of the Grandin SW 7.5 minute quadrangle showing thickness control points and isopach contours of the Upper Gasconade Dolomite. Numbers to the right of the control points are actual thicknesses. Numbers above are maximum thicknesses and numbers below are minimums.

Where discrepancies occurred during preparation of the geologic map, the attribute table and field notes were checked first for descriptive information about the outcrops. In some cases, the outcrop observations were identified as being ambiguous or questionable and the outcrop interpretation was changed to fit the structure and isopach maps. If the outcrop data was not ambiguous, the structure and/or the isopach was modified until all of the interpreted maps fit the data. Simultaneously working with these electronic overlays was much easier than working with similar overlays on film or tracing paper.

CROSS SECTIONS AND SCALED DRAWINGS

In the past, measured sections, stratigraphic columns, and other scaled drawings have been drawn in AutoCAD or by hand and then drafted in Micrografx Designer software. Redundant steps can be eliminated if geologists have a way to make these drawings directly in the computer. ArcView is much more user friendly for most of the geologists than AutoCAD, and drawings that are shapefiles in ArcView are convenient for coloring, labeling, and using either in views or layouts. Unfortunately, no acceptable way was found to make scaled drawings, directly in ArcView. This problem was partly solved by creating graph paper drawings in AutoCAD and importing them into ArcView. These graph paper templates have been used successfully to draw scaled stratigraphic columns and measured sections directly in ArcView. The graph paper background can be turned off for display or printing.

Experiments are currently underway using AutoCAD Map 3.0 to draw the scaled elements of cross sections. AutoCAD Map has the capability to rotate a DRG. By rotating the DRG until the line of the desired cross section is in a horizontal position, it is possible to place a scaled grid along the line and use the cursor cross hairs to plot the topographic profile and position of geological features. Once the scaled aspects of the drawing are complete, the drawing can be returned to ArcView to fill in detail, text, and color. Other software alternatives are also being reviewed including the use of a USGS DEM in Arc/Info and 3D Analyst ArcView Extension.

COMPILATION OF COMPOSITE MAPS

Missouri has 6 geologists assigned to map 7.5 minute quadrangles as part of the STATEMAP project. We have geologically mapped adjoining quadrangles within a 1:100,000 quadrangle area and then compiled the individual 7.5 minute maps into the composite map for publication. The first of these composite maps is being completed this year. It includes 13 maps that were drawn originally in ArcView and 19 maps that were drawn on mylar with ink and then digitized using GSMAP.

The maps drawn in ArcView were the simplest to compile. Individual geologists were responsible for assuring that their maps match along all of the common boundaries. This was easily accomplished in ArcView by adding the shape files from the adjoining quads to each map. Where discrepancies occurred, the geologists involved resolved the problem. In most cases it was a matter of one geologist having control where the other didn't and the map that lacked data was modified to fit with the one with the best control. In a few cases, the discrepancy was a difference in interpretation and occasionally required the geologists to return to the field together and come up with a mutually acceptable interpretation. In either case, the corrected and matched shapefiles were sent to the geologist making the compilation.

The data digitized in GSMAP was more difficult to handle and much less accurate. The data was imported into ArcView as dxf files in the form of polylines, rather

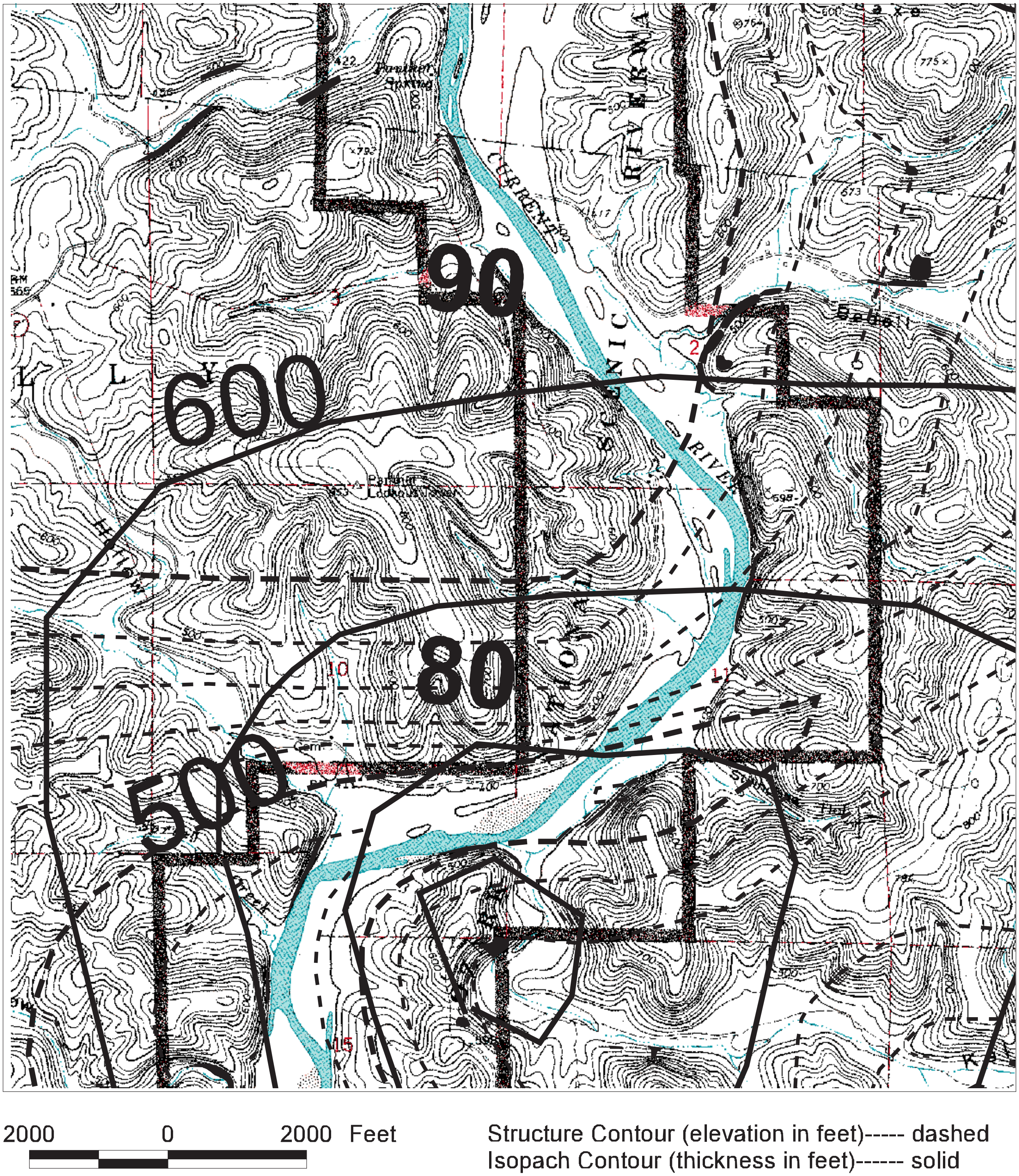

Figure 4. In this clip from near the center of the Grandin SW 7.5 minute quadrangle, the structure map, isopach map, outcrop map, and topographic map are combined to provide control for drawing the formation contacts for the geologic map. The structure contours are color coded with the even 100 foot contours as red and each of the other contours (20, 40, 60, and 80) as other distinct colors that can be easily seen and remembered. This facilitates interpolation between the contours when only 1 or 2 are visible at the scale that the map is being drawn (usually between 1:4000 and 1:8000). The heavy angular line is the boundary of the Ozark National Scenic Riverways.

than polygons. It was necessary for a technician to close these lines and convert them to polygon themes before the compiling geologist could work with them. The quality of the digitizing varied from excellent to poor and the geologist making the compilation had to frequently refer to the original inked map to determine how to edit the boundary areas to make them match. Another problem was that some of the authors of these early maps are no longer with the Geological Survey Program and could not help with resolving boundary discrepancies. The compiling geologist had to make the best interpretation possible from the existing maps.

Future compilations should be much easier with all of the maps drawn, edited, and matched along the boundaries by the original mapping geologists using ArcView.

LAYOUTS AND PRINTING

Procedures for preparing the layout for the final printed map have evolved as well as the mapping techniques. Last year, the final product was a composite of drawings and tables prepared by drafting personnel, copied segments from text files, and graphics drawn in ArcView. Cross sections and stratigraphic columns were drawn by hand and turned over to the drafting department. Drafted illustrations were prepared using Micrografx Designer software and exported to ArcView as eps files. These files were then edited in the layout.

The geologists involved in mapping met frequently to develop standards so that all the maps would be as similar as possible. Now that the standards have been established and with the new techniques for the scaled drawings, most of the layouts are being prepared directly by the geologists in ArcView. Composite stratigraphic columns, legends, and templates are being prepared that will allow each geologist to clip those parts that are needed for his or her map and edit them as needed. Drafting support will be minimal.

SUMMARY

The Geological Survey Program in Missouri has found that mapping by geologists directly in ArcView has resulted in a significant improvement in map accuracy and boundary compatibility. Plotting the correct elevation of geological contacts depends on structure, unit thickness, topography, and outcrops. All of these features can be mapped, and then viewed and edited simultaneously in ArcView, facilitating the geological interpretation. Compilation of maps is easier when each mapping geologist compares his or her mapping with the shape files of adjacent maps and resolves any boundary discrepancies. While AutoCAD is required for some scaled drawing, templates imported from AutoCAD allow most geological work to be done within the simpler environment of ArcView. Preparation of layouts by geologists within ArcView eliminates much of the need for drafting support and the redundancy of penning draft drawings to be digitized or drafted by others. The program has proved to be very user friendly and geologists with little computer background were able to pick up the techniques and successfully complete their map assignments within the first year.

Digital Resource Database for Management Decisions in City of Rocks National Reserve

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INTRODUCTION

The City of Rocks National Reserve, jointly administered by the National Park Service, Idaho Department of Parks and Recreation, and local authorities, received the national attention to designate it as a Reserve largely because of its position on historic emigrant routes, including the California Trail. Emigrants passing through the stunningly scenic landscape of giant rock spires and pinnacles dubbed the area the "Silent City of Rocks" and signed their names on many pinnacles. As a result, geology has a key place in the founding of this Reserve, for the geologic landforms led to the cultural resources. Geology also is a key contributor to land-resource management decisions, because the susceptibility of surface materials to erosion, deposition, and destructive processes such as landsliding require geological study. The surface materials also partly control vegetation distribution and habitats, and may influence invasion of exotic species.

We developed custom geologic databases for the City of Rocks so that they can be used in GIS systems with other databases. The datasets have been organized in an ArcView GIS project, a commercial Geographic Information System (GIS) package (Environmental Systems Research Institute, Redlands, California), that simplifies the loading, display, and use of the databases. The database and ArcView project have been developed with the idea that users are not geologists, but do have uses for scientific geologic information. A geologic map database can be plotted on a contour map base to create a standard geologic map. In this mountainous area geology has a strong correlation to terrain, so the geologic map can also be presented as a composite with shaded relief. Maps created from susceptibility models for many geologic processes in the area display areas with potentially high vulnerability to destructive processes such as erosion and rock falls. Physical inventory databases have also been created, such as an inventory of pinnacles and other granitic landforms, and an associated photographic inventory that documents the present state of granitic and related surficial features. The databases are in the final stages of production, as is the development of the ArcView application. Management staff at the City of Rocks has showed strong interest in the database, to be released later this year, and in the ongoing development of scientific research and development of resource applications in the Reserve. The databases will likely be incorporated into an Internet Map Server application that may include virtual field trips and other interpretive information.

GEOGRAPHIC AND HISTORIC SETTING

The City of Rocks, located near the town of Almo in the Albion Mountains of south central Idaho, was established as a National Reserve in 1988 to preserve cultural and natural resources that attracted commentary in the journals of emigrants to California over a 50-year period in the 19th century. By far the most important part of the emigration through City of Rocks was caused by the Gold Rush of 1849, which led to pioneer wagon trains for several more decades. In addition, the Salt Lake Alternate Trail passed through the southern part of the Reserve, joining the California Trail there in Emigrant Canyon. This trail also was used for several decades as part of the stagecoach route between Salt Lake City and Boise. The emigrants not only commented on the fantastic pinnacles but also on lush green fields and abundant water for their cattle and oxen. They covered pinnacles near the trail with names of rocks, their own names, and other graffiti. Some of these inscriptions remain as a reminder of the past travelers.

At the City of Rocks, geology is a focal point for cultural and natural resources, as well as for recreation. The cultural resources range from the original emigrant routes through late 19th century settlements and the subsistence lifestyles of the early American west. Emigrants took note of the area because of the pinnacles and abundance of water, both being attributes of the geology that formed the Albion Mountains. Members of early communities adapted their lifestyles to the offerings of the land, whether availability of clay for brick making, stone for building, or water for irrigating. Geology has a fundamental influence on natural resources as well, since the geology controls landforms, and these landforms influence the plant and animal communities. Geological features are also noted for their recreational values. The eroded granitic terrain harbors a maze of spires, which are popular among climbers. However, the granitic sediments of the area are not able to withstand many land-use practices, resulting in eroding sections of trails and roads and diminishing wildlife and vegetation.

GEOLOGIC DATABASE

In addition to the geologic features that have interested travelers and local communities, City of Rocks has attracted geologists because it is a metamorphic core complex. The region was identified as early as 1968 as an area of at least three phases of early-mid Cenozoic regional deformation events which included denudation by crustal extension accompanied by emplacement of granite (Armstrong, 1982). The topic of metamorphic core complexes was widely debated in the 1970's and still attracts many researchers to the western United States, and to the core complexes in and around the City of Rocks. Contrasted to the mid-Cenozoic deformation and accompanying mountain building, research for this study suggests that the three main upland basins in the City of Rocks are relatively stable. For instance, they accumulate alluvium and colluvium very slowly. However, the area is not necessarily stable. Processes such as soil creep, landsliding, and debris flows can impact areas that appear to be quiescent.

The geologic database consists of an Arc/Info (Environmental Systems Research Institute, Redlands, California) format dataset that represents bedrock and surficial deposits for the City of Rocks. Geology was mapped at 1:24,000 scale and larger when necessary. Much of the recent mapping was done using GPS and in-field databases to improve accuracy and increase efficiency of mapping. The digital field systems used for much of the mapping consists of a PLGR GPS unit with an average 8m locational accuracy, and a PalmPilot handheld computer running a database package which serves as the geologist's notebook. Because notes and positional information are acquired digitally and accurately, they allowed daily mapping information to be downloaded into a laptop computer at the end of each day and incorporated into a spatial database of observations. Nightly updates to the geologic map were performed using the daily observations and Digital Orthophoto Quadrangles in ArcView GIS, using ArcView's on screen digitizing capabilities for shapefiles. When mapping was completed, the geologic map was imported into an Arc/Info database, and topological errors inherent in shapefiles were corrected. The database consists of a geologic units and faults layer, structural layer, and cross-sections; all are viewable in ArcView or other GIS packages.

GEOLOGIC STABILITY MODELS

Stability models for several types of geologic processes were developed to help land managers at the City of Rocks to understand the interactions of terrain, geologic materials, vegetation and climate. These models can be combined with other survey data such as vegetation assemblages and animal habitat to develop more comprehensive models for determining management alternatives for uses such as: grazing allotment decisions, facilities siting, road and trail siting, fire management, water use, drainage diversion decisions, and developing monitoring strategies. Input data sets for the susceptibility models include data from: 1) U.S. Geological Survey (30 meter Digital Elevation Models, Digital Orthophoto-Quadrangles, and topographic maps): 2) Soil Conservation Service (Soil survey of part of Cassia County, digitized in ArcView); and 3) custom data from field studies (bedrock geology and surficial materials, and landforms).

The basic form of each model is a series of geologic, terrain, and climatic factors that are numerically modeled to create an output susceptibility map. Input factors are individually weighted to classify each factor into an appropriate scale (for instance, slope is continuously changing data, but there may be threshold slope values that need to be expressed in the models). Individually weighting each factor in the model also puts all the data into the same range of values. This is important in order to numerically compare factors: if a geologic unit is 'late Pleistocene alluvium', and you want to model the slopes on that unit, you have to convert a text attribute into a numerical attribute. Similarly, to compare erosion potential between bedrock units and surficial units, the units must be weighted against each other so that surficial units will be more susceptible to erosion. Each factor is classified and assigned numerical values based on theoretical and experimental studies from the literature, from knowledge of geologic processes, and from inferences based on geologic deposits and other information at the Reserve. Once each factor is individually weighted and in the same range of values, an equation can be developed that weights each factor against the others. This equation is then evaluated on a pixel-by-pixel basis to arrive at the final result, which is classified by inspection and calculation into categories of high, medium, and low susceptibility and displayed in map form. Figure 1 illustrates this process. Although the models are essentially empirical, they yield numerical results that can be used to test and calculate statistical measures of suitability, should those approaches be desirable.

The models display areas with potentially high vulnerability to destructive processes (Figure 2), particularly if the land is disturbed (such as by wildfire, road building, and drainage diversion). Simple GIS overlays of these maps provide guides to making land-use decisions, such as routing a road. The models are created using Arc/Info's GRID module, which performs raster-based analysis. Results of the models can be viewed as images within ArcView, or converted into a vector format to allow the model results to be queried. The models can be improved by collecting better quality information on soils, more detailed slope maps, and better precipitation data.

PINNACLES AND GRANITIC LANDFORMS DATABASE

The most notable landform features of the Reserve are the prominent, steep-sided, smooth and rounded granitic pinnacles. The name City of Rocks refers to this assemblage that resembles the assortment of tall and short buildings found in a city. These rock features are as high as 500 feet and are found across nearly 2000 feet in elevation from low basins to high ridges. Most pinnacles have formed in the granite of the Tertiary Almo pluton. Joints oriented nearly north-south are the most strongly developed, causing many of the pinnacles to be elongate north-south. Convex upward, dome-shaped joints and nearly horizontal joints are believed to be responsible for the two

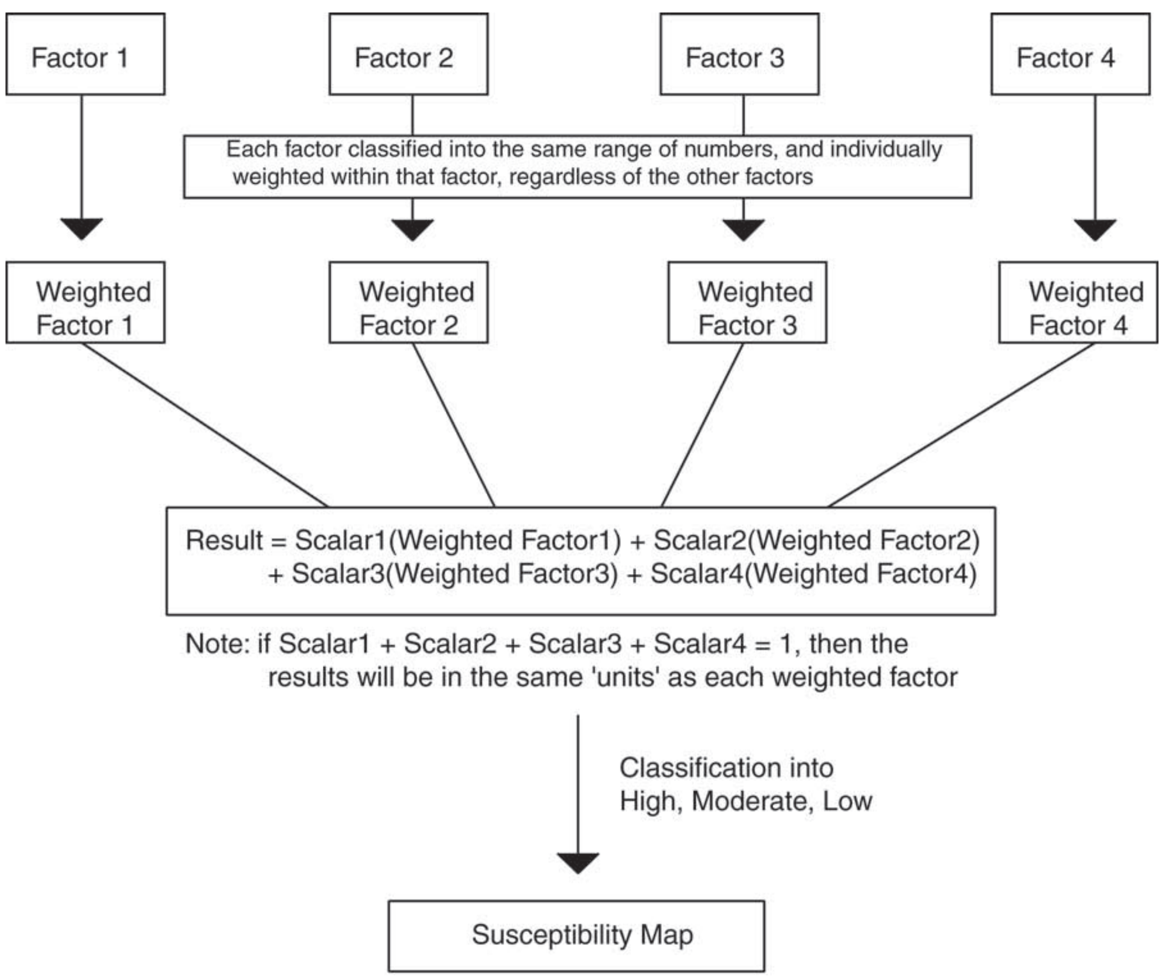

Figure 1. Flow diagram illustrating the Geologic Susceptibility Models.

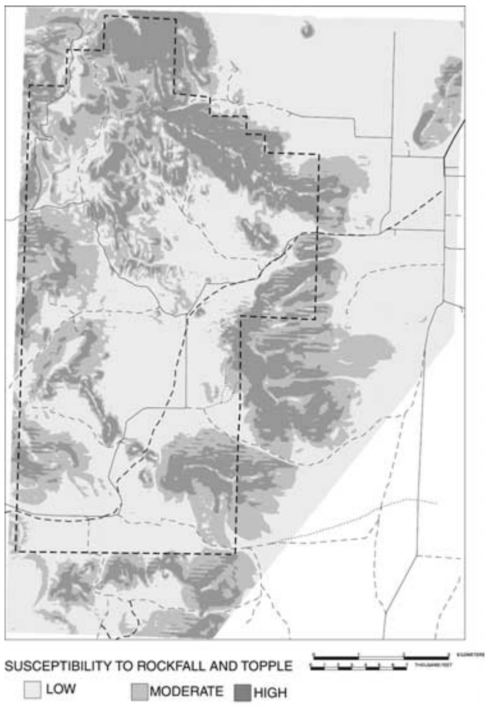

Figure 2. Sample susceptibility map showing the reserve boundary and roads in the Reserve.

main types of geomorphic features in the pinnacles: bornhardts and tors respectively (Cunningham, 1971).

The pinnacles and granitic landforms database represents outcrops of granite features with abrupt topographic relief on one or more sides, as distinct from exposed pediment and other nearly flat granite features. The location of pinnacles were "heads-up" digitized using ArcView GIS, and then converted into Arc/Info format. Digital Orthophoto Quadrangles of the Reserve were used as a base for digitizing the polygonal outlines of the bases of pinnacles within the Reserve. Stereoscopic viewing of multiple years of aerial photographs (1956 - 1992) aided in distinguishing granite features of raised relief from exposed pediment and rock fall. Digitizing was done at variable scales from 1:3,000 to 1:10,000. Field checking was performed in many areas during the photographic documentation of granitic rock features.

A spatial inventory of location of granite rock outcrops having raised relief can be used for a variety of purposes, including base map applications and spatial analysis in a GIS. Base map applications include: identifying and locating (1) rocks with names, (2) pinnacles used for climbing, (3) rocks bearing inscriptions, and (4) rocks with unique, rare or fragile features. The database can also be used to: (1) prepare thematic maps (or pamphlets) using prominent pinnacles as selected reference points, (2) reference features or landmarks on trail maps or climbing guides, (3) prepare road maps, and (4) aid in search and rescue operations. Below we describe its use in a rock and fragile feature inventory.

This digital database can be used in ArcView, or other GIS packages, to query for relationships with other GIS datasets for interpretation, resource management, maintenance, and design & development applications. This dataset can also serve as a base map for baseline inventory of other resources (e.g. wildlife habitat; pack rat midden localities; inscription rocks; climbing rocks, etc).

INVENTORY AND PHOTOGRAPHIC DATABASE OF SPECIAL FEATURES

The pinnacles database was used to initiate a rock/fragile feature inventory. This database provides photographic documentation of many of the landforms in the Pinnacles database. The photographs document the present condition of features that appear to be fragile, including rock faces undergoing frequent climbing activity and special wildlife habitat situations related to the shapes of landforms. The database contains features such as woodrat middens, natural arches and windows, precariously balanced rocks and rock shelters. The photographic database contains two types of images: photos of a particular feature, and sets of photos that are of vistas or panoramas. Photos of vistas are symbolized and queryable in ArcView by both the location that the photo was taken from, and the general direction the photo is depicting (Figure 3).

Photographs were taken using a digital camera and aerial photographs and topographic maps were used to note the location of each photo. A short description of the features seen in the photograph was incorporated into the database, as well as common keywords that can be attributed to many photographs to allow ease of querying the database for a particular theme found in the photos. The photographic database is implemented in ArcView through the use of hotlinking: when a user clicks on a point or points in the photographic database, all photos associated with that point are automatically loaded into separate windows within ArcView. Further modifications to the ArcView project will probably automatically load the description of the photo as text at the bottom of the image. Currently there are over seven hundred photos in the photographic database, including repeat photography from the 1970's and again in the late 1990's. Another research project in the Reserve was the professional photography of nineteenth and early twentieth century rock inscriptions by the many emigrants through the City of Rocks. This database, not presently in a GIS, accentuates the inscriptions and special filtering has allowed the analysis of the inscriptions, some of which aren't visible to the naked eye. The database of inscription photography could also be incorporated into a GIS because we have provided a spatial database of rocks on which these inscriptions are found.

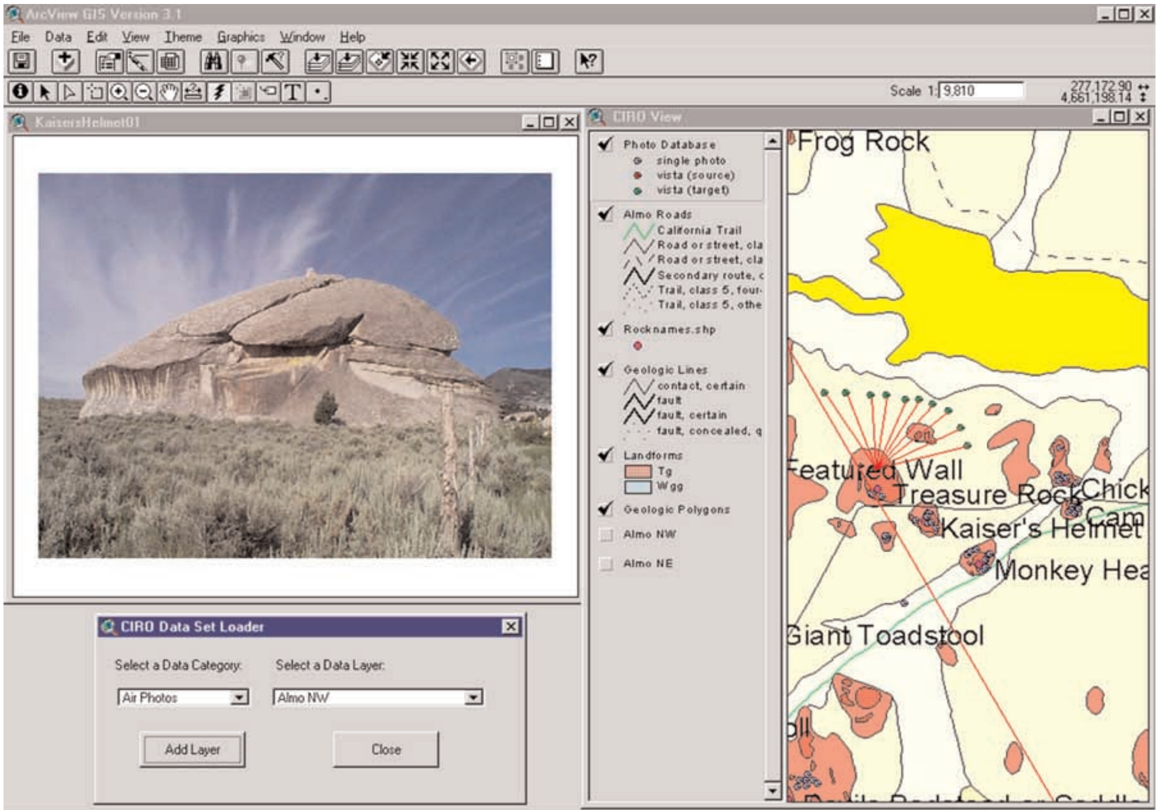

Figure 3. Screenshot of photographic database in use.

The purpose of the inventory and photographic database of special features is to document the location and current status of features considered to be fragile in the Reserve. By incorporating photography, land managers will be able to visually inspect the current conditions of these features, and in the future, will be able to analyze the changes that have occurred on these landforms. The photographic inventory provides a baseline for analysis, so that qualitative, and possibly quantitative, analysis of the degrees of impact or recoverability to these landforms will be possible.

CONCLUSIONS

Geologic oriented databases have been developed to help land managers in the City of Rocks National Reserve make more informed decisions about land use that is affected by geologic processes. Geologic databases, terrain, susceptibility to geologic processes, derivative maps, and inventories of physical resources are included in the database to give access to geologic information on a manager's desktop. A GIS system based on ArcView GIS has also been developed to promote the use of this information by simplifying the management, display, and use of these databases.

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Present and Future Issues of a Mapping Program

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INTRODUCTION

At the 1998 Digital Mapping Techniques Workshop, Gail Davidson of the Division of Geological & Geophysical Surveys presented some of the experiences and problems that the Survey has encountered during the development of a digital mapping database (Davidson, 1998). The result of this presentation was a flood of good advice from the workshop participants. Since the '98 workshop we have been putting some of those ideas to work.

WHERE WE HAVE BEEN

One suggestion offered, during the workshop last year, was the incorporation of ArcView into our mapping program. Participants from other surveys pointed out the ease of on-screen-digitizing with this software. This was seen as an attractive tool to get project and field geologists more involved in entering and processing their data. The ease with which existing data sets could be viewed and analyzed also was also seen as a useful addition to our system.

Since last year we have added ArcView to our Unix system and several of our staff now have it installed on their PC's. The result of this seems to be increased interest in data entry and manipulation by formerly "non-GIS" people. The ease with which the existing data sets can be accessed and combined offers exciting possibilities. In the past, combining old geology and new, geophysics and geochemistry, or remotely sensed data and geophysics, was something that only the "computer guys" could do on the Unix workstation. Now, the possibility exists for any geologist to manipulate the data themselves on their own PCs. Many informational maps for reports, and topographic bases for mapping purposes have been produced. ArcView will be in the field, on laptop computers, during at least one project in the 1999 field season. It is our hope that this new excitement over GIS will get our people to look at their data not only as map-specific information, but also as data that can be used in the future for analytical purposes.

While this new found enthusiasm for GIS is encouraging because of the increased efficiency in production that it can bring, it also carries with it a new set of concerns. Although ArcView is fairly user friendly and the basics can be learned very quickly, proficiency takes some time. Part of being proficient in any GIS system is an awareness of the structure of the database and how the data being generated fits into that structure. Some control has to be maintained over the way existing data is handled and where new data is stored and maintained. For instance, ensuring that data sets that are sitting on someone's PC eventually make it into the agency's server will take both discipline and training. This is not an insurmountable problem, however it is an issue that has to be addressed. Along with the overall organization of the database is the concern over the differences in formats between Arc/Info coverages and ArcView shapefiles. It isn't clear to us yet whether the difference in formats will limit what we produce in ArcView. Our existing data is in Arc/Info coverage format. Although ArcView shapefiles can be converted into coverages, it doesn't seem to be an entirely straightforward process. Can we produce polygon shapefiles and convert them to coverages without losing accuracy? Can we take coverages and convert them to shapefiles for editing purposes and convert them back to coverages all the while maintaining the integrity of the data? Before we start generating large shapefiles for use with existing data, we need answers to these kinds of questions.

Another way that we have gotten geologists in closer contact with their data is by upgrading our plotter technology. Until about 18 months ago all of our plotting was done on a Versatec plotter. This plotter was available only through the Unix system and as a result plotting jobs had to be performed by a select few people. We are in the process of phasing out the Versatec. We presently are using two HP 2500's in addition to the Versatec and by July 1 will be using the HPs exclusively. These two plotters are available through all of the PCs. Geologists are now able to plot their own test plots, informational maps, and posters directly from their desks. Because they no longer need to go through someone that knows the Sun system, it has encouraged more experimentation with data than we had seen before.

WHERE WE ARE GOING (WE THINK!)

The hot topics of conversation in the GIS/Geology world of late seem to be interactive maps and 3-D mapping. We are currently looking into putting three-dimensional views of some of the Aleutian volcanoes on the Alaska Volcano Observatory web page (http://www.avo.alaska.edu). We have also had some discussion of 3-D geologic mapping as a part of our future plans. It is difficult to try to envision exactly what these new technologies will mean to our business but one thing is certain. The trend is away from the traditional two-dimensional paper map product in favor of data packaged in digital format. Whether this means digital data on compact disks, maps served over the Web, or a combination of these and other, yet to be conceived, delivery systems, remains to be seen.

The question now is – what's the next step? We've made some headway in the past year. We are confident that many of the questions asked in this paper will be dealt with in the near future. Many of the goals we set and discussed after the workshop last year are still valid and some are becoming a reality, but what is next? What should we realistically look at as the next level in building our database and mapping program? We face some very real limitations in the future due to an oil-price driven state budget crisis. It is more important than it has been in over a decade that we are as efficient as possible and that we make that efficiency apparent to the people that we serve. The dilemma becomes how to do this and still keep abreast of the advances in technology.

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Alabama Aquifer Vulnerability CD-ROM Project: Digital Publication of GIS-Derived Map Products

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INTRODUCTION

The Geological Survey of Alabama (GSA), in cooperation with and with funding from the Alabama Department of Environmental Management (ADEM), is producing a series of interactive CD-ROMs that provide an assessment of the vulnerability of ground-water aquifers in Alabama to potential contamination from surface sources. For the purposes of this project, the state has been divided into 13 areas and a CD-ROM will be developed for each. The CD-ROM for the first area to be studied, which includes the coastal counties of Alabama (Mobile and Baldwin), has been compiled as a prototype for the series. The CD-ROM for each area will contain an interpretive report, including text, tables, figures, and plates, developed in Adobe Acrobat format; a complete suite of the GIS data sets used for, or produced as part of, the project; and other pertinent and useful data layers (United States Geological Survey (USGS) Digital Raster Graphics (DRG) topographic maps for the area, roads, streams, etc.). All GIS data produced for this project are being developed as ESRI, Inc. ArcView shapefiles, using ArcView 3.1.

The Digital Geologic Map of Alabama (1:250,000-scale) is being used as a primary source of data for the aquifer vulnerability project, and the recharge areas for the major ground-water aquifers in each area are being derived from this GIS data set. A second derivative layer delineating the level of aquifer vulnerability to surface contamination will be produced for each area.

Along with the interpretive report and the GIS data, each CD-ROM will contain ESRI, Inc.'s free GIS tool, ArcExplorer, and the Adobe Acrobat Reader. Thus, users will be able to interact with the included data regardless of the availability of a commercial GIS software package.

A key element to the successful production of the CD-ROMs for this project is the conversion of map layouts, especially plate-size maps (24" x 36" and larger), created from the GIS data sets in ArcView, to high-quality, high-resolution Adobe Acrobat (.pdf) files for digital publication. This paper will detail some problems that were encountered during this conversion process and successful solutions that were employed to achieve the desired results.

PROJECT BACKGROUND

During the mid- and late-1980s, the USGS, in cooperation with ADEM, produced a series of reports that delineates the major aquifers in Alabama and characterizes their vulnerability to surface contamination. To prepare these reports, the state was divided into 13 geographic areas and each of these was addressed in a separate report (e.g., Mooty, 1988). These reports were widely disseminated and used by ground-water resource professionals in the state, as well as by the general public. Data for the reports were compiled at the 1:250,000-scale using the best available geologic maps to delineate aquifer recharge areas. For example, one source of data for the reports was the 1926 *Geologic Map of Alabama* (1:500,000 scale), which was at that time was the most up-to-date and detailed statewide geologic map available. Further, the USGS reports were compiled and published before the widespread usage of GIS technology and thus were developed as purely analog products with little consideration given to possible future digital conversion.

In 1988, the GSA published the first statewide geologic map of Alabama based on new mapping and compilation since the 1926 map. The publication of GSA Special Map (SM) 220, *Geologic Map of Alabama* (Szabo et al., 1988) was the culmination of decades of work by numerous geologists, including not only those affiliated with

GSA, but a number of others involved in mapping the geology of Alabama for various purposes. SM 220, published at the scale of 1:250,000, comprises the largest scale and most accurate border-to-border depiction of Alabama's geology as presently understood. In 1996 and 1997, the GIS Group at GSA successfully undertook a digital conversion of the 1988 geologic map, thus providing a robust GIS data set of Alabama's surface geology (Tew et al., 1998).

By the mid-1990s, it was widely recognized that the original aquifer vulnerability reports, although having served their purpose well, were badly in need of revision and update in order to remain useful. In addition to the availability of a new geologic map for the state, numerous new data related to aquifers and ground water in Alabama had been collected in the ensuing years due to drilling of new water wells and various monitoring programs and research efforts. For example, the early 1990s saw the development of numerous wellhead protection programs around the state designed to meet the requirements of amendments to the Safe Drinking Water Act originally enacted by Congress in 1974. The 1986 amendments directed the U.S. Environmental Protection Agency to oversee the states' development of plans and programs to protect areas providing ground water to public water supply wells or springs. ADEM administers Alabama's Wellhead Protection Program (WHPP) which requires a geologic and hydrologic evaluation, delineation of wellhead protection area boundaries, and a potential contaminant source inventory for public drinking water supply wells and springs. Thus, development of the WHPP resulted in an abundance of new ground-water-related data for many parts of the state.

In 1997, personnel in the Ground Water Branch at ADEM contacted GSA relative to development of a project to update and revise the original thirteen aquifer vulnerability reports. During the course of discussions regarding the project, several desirable outcomes were enumerated. First, it was decided that the 13 geographic areas of the original reports were familiar to the user base and should be retained as the basic format for preparation of the new reports. Second, it was determined that data for the reports should be compiled at the 1:100,000 scale, where possible, rather than at the 1:250,000 scale of the original reports. Third, it was agreed that all data for the project should be developed digitally in a GIS environment, should result in useful, comprehensive GIS databases for ground water resources in Alabama, and should be fully documented with Federal Geographic Data Committee (FGDC)-compliant metadata. Fourth, it was deemed necessary that data in individual data layers should be consistent and seamless from area to area so that each layer would eventually constitute border-to-border coverage for Alabama at project completion. Fifth, it was decided that the resulting interpretive reports, GIS data, and metadata should be compiled and distributed in CD-ROM format and that the CD-ROMs should provide interactivity between the data and the user. Sixth and finally, a determination was made that the CD-ROM should include a GIS data browser so that the user would not be required to have access to commercial GIS software to interact with the included data.

To facilitate the desired project outcomes, a project plan was developed by GSA and presented to ADEM. The primary elements of the plan included the following: evaluate, revise, and recompile data from the original reports as appropriate; compile new data; develop necessary GIS data layers, including incorporation of existing digital geospatial data where appropriate; develop interpretive reports on the basis of spatial analysis and hydrogeologic research; and, publish the reports and geospatial data on an interactive CD-ROM. This project plan was approved and the project was initiated in the fall of 1997.

DIGITAL PUBLICATION OF GIS-DERIVED MAP PRODUCTS

As indicated above, GIS data layers associated with the aquifer vulnerability CD-ROM project are being developed as ESRI, Inc. ArcView(shapefiles owing to the fact that ArcView(GIS software is in widespread use among ground-water professionals and many others in Alabama. Thus, developing data in shapefile format alleviates many issues associated with data transfer and ease of use. Consequently, the majority of illustrations for the interpretive aquifer vulnerability reports, primarily consisting of maps, are being developed using the page layout tools in ArcView. These maps range from rather simple, page size (8.5" x 11") illustrations depicting one or two data themes to complex, plate size (24" x 36") maps that illustrate multiple data themes and the results of various spatial analyses and contain large areas of color and pattern fill. Although the data used to generate the maps are being provided on the CD-ROM, allowing the user to interact with the data for their own applications and visualizations, providing a high quality, high resolution, static version of each map generated by the research hydrogeologists at GSA as part of the Adobe Acrobat-formatted interpretive report for screen viewing and printing is desirable. Thus, it is necessary to convert ArcView layouts into Adobe Acrobat documents for integration in the reports. As we prototyped the project, we discovered that this conversion process is not entirely straightforward.

The most direct method to create an Acrobat .pdf file from ArcView is to print from the ArcView layout to the Adobe Acrobat PDFwriter, a virtual Postscript printer that is included with the Adobe Acrobat distribution. Using this method, print resolution is user-selectable up to 600 dpi. Basically, ArcView creates a Postscript file from the layout and sends it to the PDFwriter. The next-most direct method is to export a Postscript file from ArcView and then use Acrobat Distiller, a .pdf creation utility included in the Acrobat distribution, to “distill” the Postscript file into an Acrobat file. Again, resolution is user-selectable up to 600 dpi. Both of these methods result in beautiful, high-resolution .pdf versions of the original ArcView layouts and either method is excellent for the creation of Acrobat documents from small, relative simple layouts. However, owing to the manner in which ArcView writes Postscript, large and complex layouts such as the plate-size maps from our project take an inordinate amount of time to draw (and redraw after zooming, resizing, etc.) on the screen. An Acrobat .pdf file created from a typical plate in the aquifer vulnerability project can take two minutes or longer to fully redraw. We explored taking the ArcView generated Postscript files through a “middleware” procedure, such as opening the file in Corel Draw or other software packages and printing to the PDFwriter, as well as using the Save As command and “distilling” the resulting file through Acrobat Distiller, but these procedures did nothing to eliminate the problems with screen draws and redraws. The lengthy draw times associated with Acrobat files created from ArcView-generated Postscript were deemed unacceptable for our purposes and we set about trying to develop a workaround procedure that provided a reasonable compromise between file resolution and drawing time.

The first procedure that we explored involved using an export option from ArcView other than Postscript. The idea was to export in a format (such as JPEG) that could be read by an intermediate software package (such as Adobe PhotoShop) that could then, in turn, be used to produce the Acrobat documents using the PDFwriter. This method produced less than desirable results due to the ArcView’s limitations for export resolution in most file formats. For most formats, such as JPEG and Windows Metafile, the maximum resolution for export from ArcView is 144 dpi. At this resolution, plate-size maps are entirely too “jaggy” in appearance and, for the most part, barely legible. However, drawing times for the resulting .pdf files are extremely rapid.

On the basis of the experiences with the above procedures, it was determined that the most likely chance of success lay in identifying a software application with the capability to directly open a high-resolution ArcView Postscript file and save this file in an image format, such as JPEG, at a relatively high resolution, which could then be opened and printed to Acrobat format using the PDFwriter. We were aware that Aladdin GhostScript, a free software package (<http://www.cs.wisc.edu/~ghost/aladdin/get550.html>), had the ability to work with, and convert between, a number of file types and so we decided to experiment with GhostScript to determine if its capabilities suited our needs. We acquired a copy of GhostScript 5.50 for Windows NT and its graphical interface module, GSView 2.70, and immediately determined that the package could open an ArcView PostScript file. Further, GhostScript has the capability to “print” the open file to a 300 dpi JPEG file. We worked through this procedure with one of the large, complex maps from the aquifer vulnerability project and opened the resulting file in Adobe PhotoShop LE. The quality of the JPEG image was excellent. However, file size was rather large owing to the fact that the GhostScript JPEG file contained red/green/blue (RGB) color. To reduce file size, the RGB file was changed to Indexed Color within PhotoShop LE. We then printed the file to the PDFwriter and opened the resulting Acrobat file with Acrobat Reader to test legibility and resolution, as well as drawing time. The file opened quickly, redrew quickly, and the overall quality was quite good. Thus, the experiment using GhostScript as a “middleware” application was successful. Subsequently, we have used this procedure to produce Adobe Acrobat files from ArcView layouts with excellent results.

SUMMARY

The joint GSA/ADEM aquifer vulnerability CD-ROM project required the digital publication of map products generated from layouts in the ArcView 3.1 GIS software package as Adobe Acrobat .pdf format files. Direct conversion of ArcView layouts to Acrobat files, especially when dealing with large, complex map compositions, proved to result in Acrobat files that were unacceptable due to inordinately long draw and redraw times. Several procedures were explored in attempts to address this problem, but most resulted in quick file draw time, but unacceptable maps due to low resolution. One procedure, however, employing Aladdin GhostScript 5.50 for Windows NT and Adobe PhotoShop LE as “middleware” applications, resulted in Acrobat format files that opened and redrew quickly and were of high quality in terms of resolution. Thus, a successful methodology for digital publication of large, complex ArcView map layouts in Adobe Acrobat format was developed.

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Geologic Resources Inventory for the National Park System: Status, Applications, and Geology-GIS Data Model

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SUMMARY

Over the past year, the National Park Service (NPS) has initiated a geologic resources inventory (GRI) to document and evaluate the geology of about 265 national park (N.P.), national monument (N.M.), national recreational area (N.R.A.), national historic site (N.H.S.), and other units of the National Park System (Gregson, 1998). Geologic resource workshops were held for park units in Colorado, and new user-friendly GIS tools were developed for a pilot digital geologic map project at Black Canyon of the Gunnison National Monument (BLCA) and Curecanti National Recreation Area (CURE). The NPS-developed cross section and legend text display tools are an integral part of a standard geology-GIS model that is in development. The evolving geology-GIS model is based on the Washington State Arc/Info GIS data model (Harris, 1998) that is being adapted for ArcView GIS and extended to include components of the AASG/USGS Draft Digital Geologic Map Data Model (GMDM) (Johnson, Brodaric, and Raines, 1998). Cooperative projects for NPS units in Colorado, Craters of the Moon National Monument, and City of Rocks National Reserve are planned or in work, and scoping workshops are scheduled for park units in Utah during 1999.

INTRODUCTION

Bedrock and surficial geologic maps and information provide the foundation for studies of groundwater, geomorphology, soils, and environmental hazards. Geologic maps describe the underlying physical habitat of many natural systems and are an integral component of the geophysical inventories stipulated by the National Park Service (NPS) in its Natural Resources Inventory and Monitoring Guideline (NPS-75) and the 1997 NPS Strategic Plan. The NPS Geologic Resources Inventory (GRI) is a cooperative endeavor among the NPS Geologic Resources Division (GRD), NPS Inventory and Monitoring (I&M) Program (Natural Resource Information Division - NRID), U.S. Geological Survey (USGS), and individual state geological surveys to implement a systematic, comprehensive inventory of the geologic resources for NPS units. The NPS Geologic Resources Inventory for the 265 selected park units consists of four main phases:

1) a bibliography (GeoBib) of geologic literature and maps,

2) an evaluation of park geologic maps, resources, and issues,

3) the acquisition and production of digital map products and information, and

4) a report with basic geologic information, hazards and issues, and existing data and studies.

STATUS OF GEOLOGIC RESOURCES INVENTORIES

The NPS GRD and I&M Program sponsored a Baseline Geologic Data Workshop in Denver in the fall of 1997 to get input from NPS, USGS, state survey personnel, and cooperators about basic geologic data needs that could be provided by the I&M Program. At the Denver meeting, Colorado, Utah, and North Carolina were chosen as pilot project states to maximize cooperation among the agencies. The group discussed and adopted the four main inventory phases which are reviewed briefly below.

The GeoBib project is completing the initial phase of data collection for existing geologic resources (maps and literature) in each NPS unit and publishing the data on the Internet (URL: http://165.83.36.151/biblios/geobib.nsf LOGIN: geobib read PASSWORD: anybody). In addition, index maps showing the location of associated geologic maps have been prepared for the parks in Colorado and Utah. In general, after map coverage for each park is determined, map products can be evaluated, and if needed, additional mapping projects identified and initiated.

Pilot geologic issues/map scoping workshops (with attendees referred to as Park Teams) were organized in 1998 to evaluate the resources in Colorado parks and will continue with projects in Utah during 1999. Park Teams evaluate existing maps for existing and potential digital products and identify any new geologic mapping needs. New geologic mapping projects may be initiated on a case-by-case basis after careful evaluation of park needs, costs, potential cooperators, and funding sources.

GRI cooperators are also assisting with geology-GIS standards to ensure uniform data quantity and quality for digital geologic maps. In addition to standardized data definitions and structure, NPS resource managers also need user-friendly GIS applications that allow the digital geologic map products to "look and feel" like the original published maps. Ongoing pilot digitization projects are providing additional experience and test beds for the geology-GIS model.

Park workshops suggest several applications for park resource management from an enhanced understanding of the parks' geology. Examples include the use of geologic data to construct fire histories, to identify habitat for rare and endangered plant species, to identify areas with cultural and paleontological resource potential, and to locate potential hazards for park roads, facilities, and visitors. Digital geologic maps will enhance the ability to develop precise hazard and resource models in conjunction with other digital data.

After completion of map inventories, a geologic report summarizing USGS, state, academic, and NPS geological literature and data will complete the project for each of the 265 park units. The geologic report content, format, and database are still being developed.

Geologic Mapping and Digitizing Projects

The NPS I&M Program has cost-shared new geologic field mapping for Zion National Park with the State of Utah. Additional field mapping projects have been proposed for 1999 to complete the geologic maps for Bent's Old Fort N.H.S., Curecanti N.R.A., Mesa Verde N.P., and Yucca House N.M. A pilot project to digitize 4 USGS geologic maps for Craters of the Moon N.M. has been completed, and the digitizing of Black Canyon N.M. and Curecanti N.R.A. geologic maps is in progress. Mesa Verde N.P. has completed a digitizing proposal, and preliminary plans are to initiate digitizing projects in 1999 for all Colorado parks with completed geologic maps.

The NPS Geologic Resources Inventory is being actively developed with the cooperation of USGS and state geological surveys. However, many opportunities for project collaboration exist that have not yet been identified, and effective communication among cooperators is a key factor for success of the inventory. Another challenge of inventory planning is the development of digital map standards that are adaptable to diverse geological conditions but still provide quality, uniform products and firm guidance for map developers. Indeed, the diversity of geologic resources found in the National Park System will provide a continuing challenge for effective project management. The National Park Service has identified GIS and digital cartographic products as fundamental resource management tools, and the I&M Program and Geological Resources Division are developing an efficient inventory program to expedite the acquisition of digital geologic information for NPS units throughout the country.

GIS ISSUES AND IMPLEMENTATION - MAKING GEOLOGY USER FRIENDLY

One of the unresolved issues facing developers of digital geologic maps and geology-GIS models is how to include unit descriptions, explanatory text, references, notes, cross sections, and the variety of other printed information that occur on published maps. This issue is particularly important to the National Park Service because there are few geologists employed at parks, and resource managers rarely have the GIS and geologic expertise needed to develop a useful product from digital layers of polygons, lines, points, and associated tabular data. The overarching development goal of the NPS I&M Program is to produce digital products that are immediately useful to anyone familiar with their analog counterparts. For geologic maps, this means that the map unit legend must be sorted and shaded appropriately by geologic age and that all textual, graphical, and other information from the published maps must be available interactively to the user. In short, the digital product must "look and feel" like its published source.

Since NPS resource managers use GIS as a tool in a wide array of collateral duties, the I&M Program is developing most digital products in ArcView GIS. ArcView interfaces effectively with other software running on the MS Windows operating system, and a new approach using the Windows help software, a MS Visual Basic graphics viewer program, the ArcView legend editor, and the Avenue script language has been developed to automate the display and query of published map information in the GIS.

GIS Map Unit Legend

In ArcView, a theme legend can be edited by selecting (i.e., double-clicking with the mouse) it in the legend. Once in the legend editor, the *Legend Type:* is set to "Unique Values," and the *Values Field:* is set to the G_AGE_NO field. The G_AGE_NO field is a numeric field used to sort the map units by geologic time and is equivalent to the GUNIT.AGE.NO field in the GUNIT.MAIN data file of the Washington State data model (WSM) (Harris, 1998) and the class_seq field in the AASG/USGS Digital Geologic Map Data Model (GMDM) (Johnson, Brodaric, and Raines, 1998). In the NPS ArcView model, this field has been replicated in the GUNIT.DBF table to facilitate automating the legend and renamed to G_AGE_NO to accommodate the dBase IV field name limitation of 10 characters. Once the *Legend Type:* and *Values Field:* are set, the individual Symbols are edited to match the published map colors, the geologic map symbol, and the unit name. After the legend is complete, it is saved to an ArcView legend file (.avl extension). In general, the 8.3 file naming convention is used to facilitate file sharing across all platforms.

Automating Map Unit Descriptions and Other Textual Information

In most GIS applications, the spatial database structure does not facilitate the use of voluminous textual data. For example, in ArcView, the database text fields only accommodate 254 characters (320 for INFO tables) which limits the ability to include lengthy map descriptions with the spatial data. Several options are available in ArcView to overcome this limitation including concatenating database fields, independent text files, linking to other database system files, and linking to a MS Windows help file. After testing several options, NPS developers have been implementing the Windows help system.

The Windows help system begins with data input or import of all the textual data from the published geologic map(s). In the Black Canyon/Curecanti pilot project, map descriptions, references, notes, and other text were aggregated from eight geologic maps. The table of contents listed all of the map unit symbols and names (equivalent to the class_label and class_desc fields of the AASG/USGS GMDM Classification Object Table) sorted by geologic age. Subsequent pages listed the map unit descriptions with one unit per page (many units had multiple descriptions from different maps) and were paginated by geologic age. At the end, references and notes from each map were entered on separate pages. Help context IDs, topic names, keywords, page numbers, and linking codes were added to the pages which were saved as a rich text format (.rtf) file. Then, the rich text file was compiled into a Windows help file.

Once compiled, the Windows help file can be opened and used with almost any MS Windows software. The table of contents has each map unit symbol and unit name "hot-linked" to the descriptions, and each description is hot-linked to the references and notes. Using the built-in Windows help tools, users can jump instantly to the table of contents, page through the age-sorted unit descriptions, search for keywords, or index the file and perform full-text searches of the entire file. The Black Canyon/Curecanti pilot project help file consists of more than 50 printed pages of information for more than 130 map units. Advantages of the Windows help file are that most text formatting, such as font, size, color, etc., are preserved in the final product, many graphics and tables are also supported, and the help system can be developed somewhat independently of the digital geologic map.

In ArcView GIS, three Avenue scripts were written to function with a toolbar button to automate the Windows help file and call unit descriptions interactively from the geologic map. The button tool is only active when the geology theme is turned on. The user selects the map unit help tool from the ArcView toolbar and clicks on the desired map unit to view the associated unit description. Using the map unit symbol (GUNIT_SYM) and the corresponding help context ID, the Avenue routine loads the Windows help file and pages to the map unit description. Thus, the map unit descriptions and other text are instantly available to the user of the digital map.

Automating the Geologic Cross Sections

Geologic cross sections are integral components of many published geologic maps and provide important spatial visualization tools to assist users with understanding the mapped geology. The I&M Program has developed a simple interactive system for displaying cross sections using ArcView and a MS Visual Basic (VB) graphics viewer program. The cross sections are scanned digital graphics files that ArcView can load and display via system calls to the VB graphics viewer program. This allows the user to interactively select the cross section(s) to view. With projects such as the Black Canyon/Curecanti pilot, the ability to quickly view some 28 cross sections throughout the area is a powerful asset toward understanding the area's geology.

To prepare the cross sections for viewing, the graphics are first scanned at 100 dots-per-inch (DPI) and saved as a digital JPEG (.jpg extension) graphics file. The JPEG format was chosen to allow the graphics to be served and viewed over the Internet in the future. Once again, the 8.3 file naming convention is used to facilitate sharing across all platforms, and file names are based on the map series designation and the designated cross section on the map (e.g., GQ1516AA.JPG is the A-A' cross section on the Geologic Quadrangle Map GQ-1516).

Although ArcView and the Avenue language provide several ways to display graphics and images, ArcView's capabilities are inadequate for efficient viewing of cross sections that could be up to 6" x 48" in size. Therefore, a simple VB graphics viewer program was developed to provide this capability. The viewer displays the graphics at 100% with the ability to scroll from one end of the section to the other.

To automate the graphics display, the cross section lines were digitized into an ArcView shape file (e.g., blcagsec.shp and associated extensions). Two text fields were added to the shape file table (e.g., blcagsec.dbf): GSEC_ID, which contains the section line (e.g., A-A'), and GSEC_FILE, which contains the complete path and filename of the cross section graphics file.

In ArcView GIS, three Avenue scripts were written to function with a toolbar button to automate the cross sections and call graphics files interactively from the geologic map. The button tool is only active when the cross section theme is turned on. The user selects the cross section viewer tool from the ArcView toolbar and clicks on the desired cross section line displayed on the map. Using the cross section line and the corresponding filename, the Avenue script loads the graphics viewer and displays the selected section. Thus, the cross sections are interactively available to the user of the digital map.

DRAFT NPS GEOLOGY-GIS DATA MODEL

As discussed above, a standard NPS geology-GIS data model is being developed based on new user-friendly ArcView GIS tools and adapted from the Washington State Arc/Info geology data model (WSM) (Harris, 1998). The NPS model will be further developed over the next year to include additional components of the USGS Draft Digital Geologic Map Data Model (GMDM) (Johnson, Brodaric, and Raines, 1998). Although the model is currently structured for Arc/Info and many details still need to be worked out, one important adaptation is to standardize the database field names to 10 characters or less that will port seamlessly among Arc/Info, ArcView, and other software compatible with the Dbase IV format. Arc/Info coverage and table names have been shortened to 7 characters to accommodate renaming the file name stem for look-up tables (e.g., CODEUNT.INF to CODEUNT1.DBF) when the stem has already been used for the spatial attributes (e.g., CODEUNT.PAT to CODEUNT.DBF). Files and field names that have been added or changed from the Washington State model (Harris, 1998) are marked with an asterisk (*). The new NPS model's data themes are listed below followed by a selected data dictionary for the five themes that have been partially adapted to date (Fig. 1). Although much work remains, final development of the NPS geology-GIS data model should be completed within the next year.

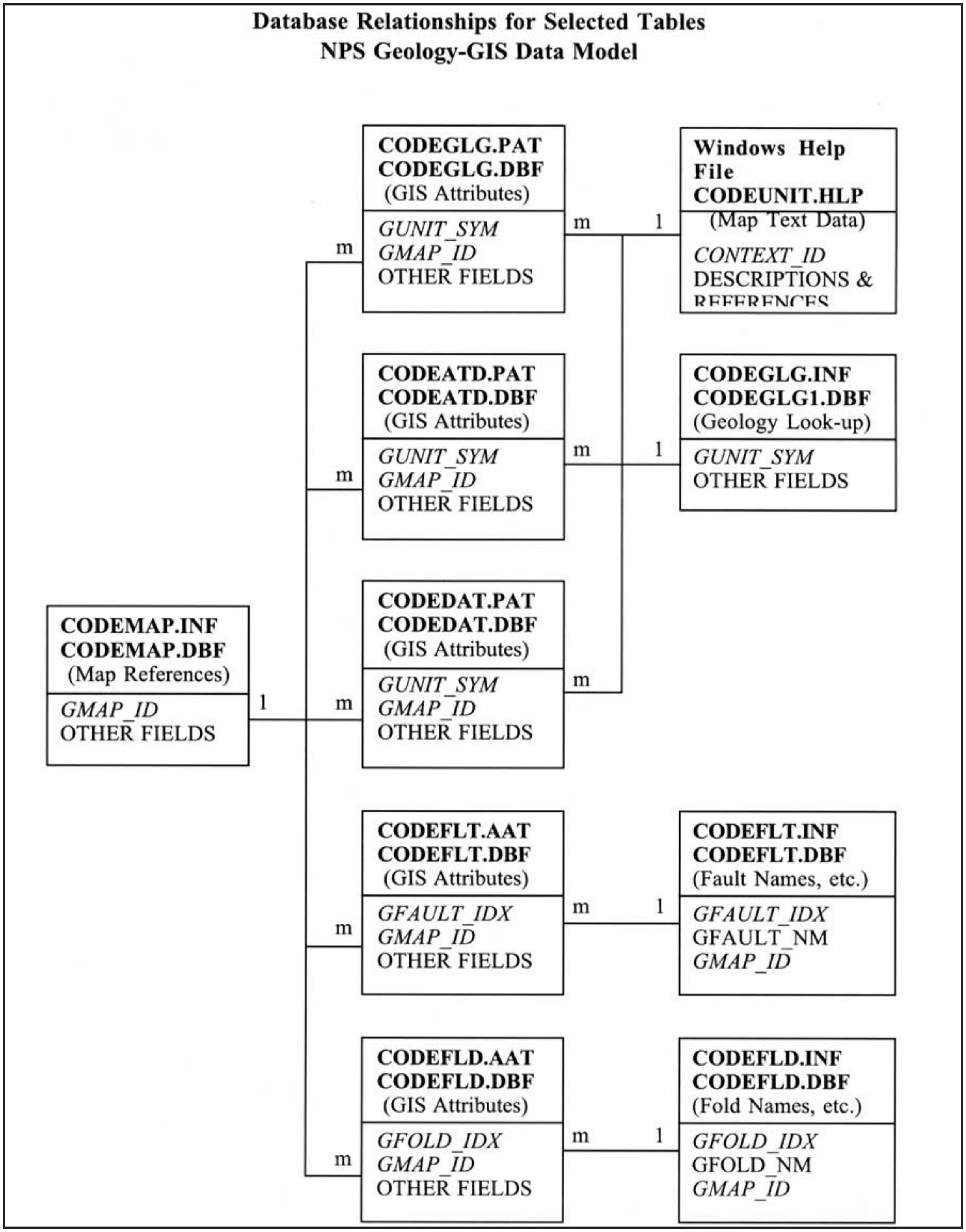

Figure 1. Simplified relationships among the database tables discussed and outlined in the text. Bold type denotes database file names for Arc/Info (top) and ArcView (below). The tabular relationships are coded with “m” for many and “1” for one. Related field names are in italics.

Coverages/Shape Files (modified from Harris, 1998)

Present work is focusing on renaming files to consistently use the 8.3 file name convention with the NPS park unit alpha code (CODE) and to limit field names to 10 characters or less.

***CODEGLG**	poly	Map units or main geologic spatial data containing both polygon data describing the map units and linear data describing the interface between those units (WSM GUNIT).
***CODEGLN**	line	Map units or main geological spatial data represented as lines due to map scale limitations (WSM GUNITLN).
***CODEGPT**	point	Map units or main geological spatial data represented as points due to map scale limitations (WSM GUNITPT).
***CODEFLT**	line	Faults and their descriptions (WSM GFAULT).
***CODEFLD**	line	Linear fold axes and their descriptions (WSM GFOLD).
***CODESEC**	line	Cross section lines and their attributes (no WSM equivalent).
***CODEATD**	point	Attitude observation points and their attributes (WSM GATTUD).
***CODEDAT**	point	Age-date sample location points (fossil or radiometric age estimates) (WSM GDTSM PL).
***CODEVNT**	point	Volcanic vents, eruptive centers, and lithologic descriptions (WSM GVENT).
***CODEDIK**	line	Individual lithologic dikes and lithologic descriptions (WSM GDIKE).
***CODEDKS**	poly	Areas of lithologic dikes too numerous to map as individual segments (WSM GDIKESWARM).

Coverages/Shape Files Data Dictionary
****CODEGLG*** (network coverage containing both arc (.AAT) and polygon (.PAT) attribution)

DATA FILE NAME: **CODEGLG.PAT or CODEGLG.DBF**

ITEM NAME	WID-TYP	DESCRIPTION
AREA	4 - F	
PERIMETER	4 - F	
*GUNIT_	4 - B	(WSM GUNIT#; automatically converted in shape file .dbf)
*GUNIT_ID	4 - B	(WSM GUNIT-ID; automatically converted in shape file .dbf)
*GUNIT_IDX	6 - I	unique number for each polygon (WSM GUNIT.ID)
*GUNIT_SYM	12 - C	age-lithology unit symbol (WSM GUNIT.LABEL.CD)
*USGS_SYM	12 - C	geologic symbol from USGS geologic map(s)
*G_AGE_NO	4 - F	number to age-sort map units (from *CODEGLG.INF table)
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

*GUNIT_SYM (map unit symbol in ASCII text; WSM GUNIT.LABEL.CD, GMDM class_label)
Age-lithology unit polygon labels. Item is also the key used to relate the *CODEGLG coverage with the *CODEGLG.INF or CODEGLG1.DBF (WSM GUNIT.MAIN) file that contains additional geologic attributes for the polygons.

*GMAP_ID (geologic map source information)
Unique integer value that relates to series and citation information of the published map in the *CODEMAP.INF or CODEMAP.DBF file.

DATA FILE NAME: **CODEGLG.AAT**

ITEM NAME	WID-TYP	DESCRIPTION
*FNODE_	4 - B	(WSM FNODE#; automatically converted in shape file .dbf)
*TNODE_	4 - B	(WSM TNODE#; automatically converted in shape file .dbf)
*LPOLY_	4 - B	(WSM LPOLY#; automatically converted in shape file .dbf)
*RPOLY_	4 - B	(WSM RPOLY#; automatically converted in shape file .dbf)
LENGTH	4 - F	

*GUNIT_	4 - B	(WSM GUNIT#; automatically converted in shape file .dbf)
*GUNIT_ID	4 - B	(WSM GUNIT-ID; automatically converted in shape file .dbf)
*GCNTCT_IDX	7 - I	unique number for each arc segment (WSM GCNTCT.ID)
*GCNTCT_TYP	1 - I	code for types of polygon boundaries (contacts) (WSM GCNTCT.TYPE.CD)
FLTCNT	1 - C	flags lithologic contacts that are also faults
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

*GCNTCT_TYP (polygon boundary/geologic contact type code)

1 known location
2 concealed location
3 scratch boundary
4 gradational boundary
5 shoreline
6 approximate location
7 quadrangle boundary
8 ice boundary
9 inferred location

FLTCNT (fault contact)

Y Yes, the fault is also a lithologic contact
N No, the fault is not a lithologic contact

***CODEFLT** (arc or line coverage)

DATA FILE NAME: **CODEFLT.AAT or CODEFLT.DBF**

ITEM NAME	WID-TYP	DESCRIPTION
*FNODE_	4 - B	(WSM FNODE#; automatically converted in shape file .dbf)
*TNODE_	4 - B	(WSM TNODE#; automatically converted in shape file .dbf)
*LPOLY_	4 - B	(WSM LPOLY#; automatically converted in shape file .dbf)
*RPOLY_	4 - B	(WSM RPOLY#; automatically converted in shape file .dbf)
LENGTH	4 - F	
*GFAULT_	4 - B	(WSM GFAULT#; automatically converted in shape file .dbf)
*GFAULT_ID	4 - B	(WSM GFAULT-ID; auto-converted in shape file .dbf)
*GFAULT_IDX	5 - I	unique ID number for each fault (WSM GFAULT.ID)
*GFLT_SEG_N	4 - I	unique number for each fault segment (GFLTSEG.NO)
*GFLT_SEG_T	3 - I	code value used to differentiate fault types and characteristics of the fault at the segment level (GFLTSEG.TYPE.CD)
FLTCNT	1 - C	flags faults that are also lithologic contacts
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

*GFAULT_IDX (geologic fault ID)

A geologic fault is commonly segmented as a result of intersecting different polygons. This item identifies an individual fault regardless of the number of segments. This item is also a key used to relate the *CODEFLT coverage with the *CODEFLT.INF file that contains fault names and data.

GFLT_SEG_T (geologic fault segment type code)

1 fault, unknown offset
2 fault, unknown offset, approximate location
3 fault, unknown offset, concealed
4 fault, unknown offset, queried
5 fault, unknown offset, approximate location, queried
6 fault, unknown offset, concealed, queried
7 And so on for 83 entries.

FLTCNT (fault contact)

Y Yes, the fault is also a lithologic contact
N No, the fault is not a lithologic contact

***CODEFLD** (arc or line coverage)

DATA FILE NAME: **CODEFLD.AAT or CODEFLD.DBF**

ITEM NAME	WID-TYP	DESCRIPTION
*FNODE_	4 - B	(WSM FNODE#; automatically converted in shape file .dbf)
*TNODE_	4 - B	(WSM TNODE#; automatically converted in shape file .dbf)
*LPOLY_	4 - B	(WSM LPOLY#; automatically converted in shape file .dbf)
*RPOLY_	4 - B	(WSM RPOLY#; automatically converted in shape file .dbf)
LENGTH	4 - F	
*GFOLD_	4 - B	(WSM GFOLD#; automatically converted in shape file .dbf)
*GFOLD_ID	4 - B	(WSM GFOLD-ID; auto-converted in shape file .dbf)
*GFOLD_IDX	6 - I	unique ID number for each fold (WSM GFOLDT.ID)
*GFLD_SEG_N	3 - I	unique number for each fold segment (GFOLDSEG.NO)
*GFLD_SEG_T	2 - I	code value used to differentiate fold types and characteristics of the fold at the segment level (GFOLDSEG.TYPE.CD)
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

*GFOLD_IDX (geologic fold ID)

A geologic fold is commonly segmented as a result of intersecting different polygons. This item identifies an individual fold regardless of the number of segments. This item is also a key used to relate the *CODEFLD coverage with the *CODEFLD.INF file that contains fold names and data.

GFLD_SEG_T (geologic fold segment type code)

1 anticline
2 anticline, approximate location
3 anticline, concealed
4 anticline, queried
5 anticline, approximate location, queried
6 anticline, concealed, queried
7 And so on for 42 entries.

***CODEATD** (point coverage or shape file)

DATA FILE NAME: **CODEATD.PAT or CODEATD.DBF**

ITEM NAME	WID-TYP	DESCRIPTION
AREA	4 - F	
PERIMETER	4 - F	
*GATTUD_	4 - B	(WSM GATTUD#; auto-converted in shape file .dbf)
*GATTUD_ID	4 - B	(WSM GATTUD-ID; auto-converted in shape file .dbf)
*GATTUD_IDX	5 - I	unique number for each point (WSM GATTUD.ID)
*GATTUD_CD	2 - I	code for type of attitude measurement (WSM GATTUD.CD)
*GATTUD_ST	3 - I	azimuth of strike or trend (0-360 degrees clockwise from the north with dip direction clockwise from strike direction)
*GATTUD_DP	2 - I	dip or plunge degrees from horizontal (GATTUD.DIP.ANG)
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

*GATTUD_CD (observation code for structural attitude point)

1 strike and dip of beds
2 strike and dip of overturned beds
3 strike of vertical beds
4 strike and dip of beds, dip unspecified
5 approximate strike and dip of beds
6 horizontal beds
7 strike an dip of foliation
8 And so on for 24+ more entries.

***CODEDAT** (point coverage or shape file)

DATA FILE NAME: **CODEDAT.PAT or CODEDAT.DBF**

ITEM NAME	WID-TYP	DESCRIPTION
AREA	4 - F	
PERIMETER	4 - F	
*GDTSM_	4 - B	(WSM GDTSMPL#; auto-converted in shape file .dbf)
*GDTSM_ID	4 - B	(WSM GDTSMPL-ID; auto-converted in shape file .dbf)
*GDTSM_CD	2 - I	code for age-dating technique (WSM GDTSMPL.METH.CD)
*GDTSM_NO	3 - I	unique code for each age sample location (GDTSMPL.NO
*GDTSM_AGE	80 - C	relative or absolute age of rock sample (WSM AGE)
*GDTSM_REM	254 - C	notes about a specific age-date sample (WSM REMARKS)
*GUNIT_SYM	12 - C	age-lithology unit symbol (WSM GUNIT.LABEL.CD)
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

*GDTSM_CD (geologic sample age-dating methodology code)

1 radiometric
2 paleontologic

*GDTSM_NO (geologic data sample number)

This item contains the sample number from the original source map. The number is used to reference additional explanatory text found on the map.

*GUNIT_SYM (map unit symbol in ASCII text)

Age-lithology unit polygon labels. Item is also the key used to relate the *CODEGLG coverage with the *CODEGLG.INF file that contains additional geologic attributes for the polygon.

*GDTSM_AGE (age of rock sample)

The age of the rock sampled expressed as a relative geologic age, such as Jurassic, or an absolute age, such as 5,000,000 years before present.

*GDTSM_REM (remarks)

Notes about the sample, such as the specific technique(s) used to determine the age of the sample.

Other Coverages/Shape Files

The other coverages/shape files listed above have not yet been evaluated or adapted for the NPS geology-GIS data model, but the renaming of files and data fields will follow a similar pattern.

Accessory Data Files

***CODEGLG.INF** (look-up data file, WSM GUNIT.MAIN)

DATA FILE NAME: ***CODEGLG.INF or *CODEGLG1.DBF**

ITEM NAME	WID-TYP	DESCRIPTION
*GUNIT_SYM	12 - C	age-lithology unit symbol (WSM GUNIT.LABEL.CD)
*GUNIT_NAME	100 - C	formal name of map unit, if any
*G_REL_AGE	5 - C	relative age code (WSM GUNIT.REL.AGE.CD)
*G_SSCR_TXT	6 - C	subscript from the map symbol (WSM GUNIT.SSCRPT.TXT)
*G_AGE_NO	5 - N	number to age-sort map units (WSM GUNIT.AGE.NO)
*G_AGE_TXT	50 - C	geologic time period of map unit (WSM GUNIT.AGE.TXT)
*G_MJ_LITH	3 - C	3 char. major lithology code (WSM GUNIT.MJ.LITH.CD)
*G_LITH_NO	4 - B	code used to sort on lithology (WSM GUNIT.LITH.NO)

*G_LITH_CD	10 - I	code used to describe lithology (WSM GUNIT.LITH.CD)
*G_LITH_TXT	100 - C	brief text describing lithology (WSM GUNIT.LITH.TXT)
*G_NOTE_TXT	254 - C	descriptive notes about the map unit (GUNIT.NOTE.TXT)
*GMAP_SRC	100 – C	GMAP_IDs of map source(s), if any (similar to GMDM source_id)

*G_MJ_LITH (map unit major lithology code)

EXT	extrusive igneous
INT	intrusive igneous
MET	metamorphic
SED	sedimentary
VAS	volcanic and sedimentary
UNC	unconsolidated

Example record from *CODEGLG.INF or *CODEGLG1.DBF (modified from Harris, 1998)

GUNIT_SYM =	Qvba(pc)
GUNIT_NAME =	Basaltic Andesite of Puny Creek
G_REL_AGE =	Q
G_SSCR_TXT =	vba
G_AGE_NO =	1.00
G_AGE_TXT =	Holocene
G_MJ_LITH =	EXT
G_LITH_NO =	39.10
G_LITH_CD =	vba
G_LITH_TXT =	basaltic andesite flows
G_NOTE_TXT =	volcanic lava flows with interbedded soil horizons
GMAP_SRC =	I-757; GQ-1082

***CODEMAP.INF** (WSM GMAP and GMAP.TXT INFO look-up data files combined/modified with Map and Source tables from AASG/USGS GMDM)

DATA FILE NAME: ***CODEMAP.INF or *CODEMAP.DBF**

ITEM NAME	**WID-TYP**	**DESCRIPTION**
*GMAP_ID	4 - I	code for relating this table (WSM GMAP.ID, GMDM map_id)
*GMAP_YEAR	4 - I	compilation or publication year (WSM GMAP.COMPILE.YR)
*GMAP_AUTH	254 - C	map author(s) (WSM GMAP.AUTHOR.YR; GMDM map_author)
*GMAP_ORG	100 – C	organization that created or compiled the map (GMDM org_id)
*GMAP_TITLE	100 - C	complete map title (WSM GMAP.REF.TXT; GMDM map_title)
*GMAP_SERIES	20 - C	map series or organizational identifier (e.g., USGS GQ-1516)
*GMAP_SCALE	7 - I	source map scale denominator (WSM GMAP.SCL)
*GMAP_PROJ	100 – C	name or description of map projection (GMDM map_projection)
*GMAP_REF	254 - C	complete map citation in USGS style
*GMAP_DESC	254 – C	brief description of the map (GMDM map_desc)
*GMAP_XMAX	7 – I	eastern limit of map in decimal degrees (GMDM map_xmax)
*GMAP_XMIN	7 – I	western limit of map in decimal degrees (GMDM map_xmin)
*GMAP_YMAX	7 – I	northern limit of map in decimal degrees (GMDM map_ymax)
*GMAP_YMIN	7 – I	southern limit of map in decimal degrees (GMDM map_ymin)
*GMAP_SRC	100 – C	GMAP_IDs of map source(s), if any (similar to GMDM source_id)

***CODEFLT.INF** (look-up data file)

DATA FILE NAME: **CODEFLT.INF or CODEFLT1.DBF**

ITEM NAME	**WID-TYP**	**DESCRIPTION**
*GFAULT_IDX	5 - I	unique ID number from *CODEFLT (WSM GFAULT.ID)
*GFAULT_NM	60 - C	fault name, if any (WSM GFAULT.NM)
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

***CODEFLD.INF** (look-up data file)

DATA FILE NAME: **CODEFLD.INF or CODEFLD1.DBF**

ITEM NAME	WID-TYP	DESCRIPTION
*GFOLD_IDX	5 - I	unique ID number from *CODEFLD (WSM GFOLD.ID)
*GFOLD_NM	60 - C	fold name, if any (WSM GFOLD.NM)
*GMAP_ID	4 - I	code for *CODEMAP.INF look-up table (WSM GMAP.ID)

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Gregson, Joe D., 1998, Geologic Resources Inventory—Geologic Resources Division, Inventory and Monitoring Program, in David R. Soller, ed., Digital Mapping Techniques '98—Workshop Proceedings: U.S. Geological Survey Open-File Report OFR 98-487, p. 109-111, <http://pubs.usgs.gov/openfile/of98-487/gregson.html>.

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Johnson, Bruce R., Boyan Brodaric, and Gary L. Raines, 1998, Draft Digital Geologic Map Data Model, Version 4.2: Association of American State Geologists/U.S. Geological Survey Geologic Map Data Model Working Group Report, May 19, 1998, <http://ncgmp.usgs.gov/ngmdbproject/>.

Examples of Map Production from the Alaska Division of Geological and Geophysical Surveys

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As new technologies emerge, methods of producing geologic maps and other informational products are being refined and updated. At the Alaska Division of Geological and Geophysical Surveys, maps are produced on-demand from either an electrostatic or an HP design jet plotter. Growth of the geologic database and increased availability of outside data sources have led to increased efficiency in the production of geologic maps, derivative maps, and other products. The use of Arc/Info in conjunction with PC-based drawing and layout software has proven to be an effective method of producing a high quality product.

Two examples of projects are displayed. Information Circular 38, Volcanoes of Alaska was produced by DGGS in conjunction with the Alaska Volcano Observatory. The base map consists of hypsography from State of Alaska, Land Records Information Section (LRIS) Arc/Info grids, coastline from LRIS ArcInfo coverages, and bathymetry from USGS open file maps, combined using Arc/Info. The text was written by USGS and DGGS personnel and laid out using Adobe Pagemaker. The geologic map of the Horn Mountains area in southwestern Alaska is the result of field work carried out during the 1990, 1991, and 1992 field seasons. The geologic data was digitized in Arc/Info and converted to an EPS file. The surrounding text files are each individual Adobe Illustrator EPS files. All of these files were then linked in a single Illustrator file, in layers, with one EPS file per layer. The file was then sent to an HP plotter with the PostScript (optimized for portability – ADSC) option chosen.

Over the past year, we have found new ways of combining Arc/Info map data with PC drawing and layout programs. These methods allow us to publish maps with sophisticated layouts more quickly, while still retaining our underlying Arc/Info database.

Geologic Map of the Monterey 1:100,000 Scale Quadrangle and Monterey Bay: A Digital Database

By David L. Wagner[1], H. Gary Greene[2], Jason D. Little[1], Sarah E. Watkins[1], and Cynthia L. Pridmore[1]

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A new geologic map of the Monterey 1:100,000 scale quadrangle and Monterey Bay is being compiled by the California Division of Mines and Geology and Moss Landing Marine Laboratory. The map is a digital database which, for the most part, was digitized at 1:24,000 scale using ALACARTE, a menu-driven module developed by the U.S. Geological Survey running on Arc/Info GIS software. This project was supported in part by the U.S. Geological Survey through its National Cooperative Geologic Mapping program, STATEMAP component.

The map was prepared using the technique described by Wagner at DMT '97. Onshore, existing geologic maps, mostly at 1:24,000 scale were digitized and tiled together to make up the 1:100,000 scale map. An earlier analog version of the map was used as a guide to correct boundary problems between quadrangles. A DEM with 30 meter resolution was used for a shaded relief basemap using the technique described by Ralph Haugerud and Harvey Greenberg at DMT '98.

Offshore, a wealth of new geologic information was available. These new data were overlain on new high resolution bathymetry acquired by the Monterey Bay Research Institute converted to a shaded bathymetric base.

REFERENCES

Haugerud, Ralph, and Greenberg, Harvey M., 1998, Recipes for Digital Cartography: Cooking with DEMs, *in* David R. Soller, ed., Digital Mapping Techniques '98 — Workshop Proceedings: U.S. Geological Survey Open-File Report 98-487, p. 119-126.

Wagner, David L., 1997, Digital mapping techniques employed by the California Division of Mines and Geology, *in* David R. Soller, ed., 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, p. 35-38.

Geological Map Production at the Geological Survey of Canada

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ABSTRACT

The Cartography Section of the Geoscience Information Division produces geological maps encompassing a variety of geo-scientific data. The Cartographic Database Standards (CDS) ensures that this data is managed in an efficient manner for map production and archival purposes. The benefits of CDS allow geologist and cartographers to integrate and update data seamlessly, provide consistent and uniform digital data to the geoscience community, and ensure that map production is portable between cartographers. While CDS forms the framework of digital geological data, the Geological Mapping System (GEMS) is the tool cartographers use to create the geological maps. Essentially, GEMS is comprised of programs and a graphical user interface that adapts the cartographic database standards and utilizes the strengths of Arc/Info in a map production environment. Benefits of such a system are to increase productivity by using universal methods and applications, and lessen the learning curve of software as complex as Arc/Info. Further information on CDS and GEMS, including downloading possibilities can be obtained from <http://www.NRCan.gc.ca/ess/carto> in the Procedures and Specifications section.

A Digital Geologic Map Data Model Designed for GIS Users

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ABSTRACT

Geologic maps are an invaluable source of spatial data about surface and subsurface geology, and are increasingly used by non-geologists. Notably, most GIS-capable agency, industry, and education units seek geologic maps and digitize or import them into their systems. Geologic maps are a challenge to understand, and many well-trained GIS analysts and technicians lack an understanding of the scientific methods behind the interpretations on a geologic map. This can lead to misuse of the data, especially when the data are in digital form.

Based on the USGS model, we are designing geologic map products that meet the needs and expertise of the GIS community. Digital geologic maps are more than digitized lines, symbols, and polygons. Without explanation, those spatial data have little value. The digital product (digital geologic map) consists of spatial databases (composed of lines, polygons, and symbols), and a digital explanation database. The digital explanation consists of a hierarchy of tables that are linked to each other and are linked to the components of the spatial database. The power of a digital explanation is giving the user the ability to "query" or search the database, and generate a derivative version of the map. For example, one can search and select parameters such as lithology, stratigraphy, origin, landform, weathering, relative age, radiometric age, and sources of data (field mapping). Authors of digital geologic maps may include other parameters such as magnetic polarity, soil series, and hydrologic characteristics. This system of organizing the scientific information that comprises a geologic map provides a new way to present geologic observations and interpretations that will aid in the educated use of these data.

IGS DATA MODEL DEVELOPMENT

The Idaho Geological Survey (IGS) is developing a derivative model based on the proposed USGS data model (version 4.2). The IGS model uses the ARC/INFO GIS spatial database as its core. IGS has several goals to achieve in the development of a Geologic Map Data Model and the user tools associated with it:

* The data model and the organization of the resulting digital geologic maps should be driven by the science of geology.

* In addition to creating the map and writing a legend and explanation, the geologic map author should have direct involvement in composing the database fields.

* To achieve the above goals, we need to develop a set of user-friendly input tools.

* The model should be flexible, expandable, and eventually transferable to the final model standards proposed by the Data Model Steering Committee or its technical working groups.

* Easy-to-use tools need to be developed for queries and low-level analysis in a GIS package like ArcView.

Development of the IGS model began in September 1998. Currently we have a prototype which is being modified. A prototype query engine tool has also been written.

Digital Geologic Map of the Harrodsburg 30 x 60-Minute Quadrangle, Central Kentucky

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The digital geologic map of the Harrodsburg 30 x 60 minute quadrangle was compiled from 32 U.S. Geological Survey 7.5-minute geologic quadrangle maps (GQ's). The GQ's are products of a cooperative mapping project between the U.S. Geological Survey and the Kentucky Geological Survey from 1960 to 1978. This map is a compilation of existing maps, and no additional geologic field work took place. When there were problems in stratigraphic correlation between quadrangles, the best current data available were used to resolve these differences.

The geology of the mapped area consists of flat-lying sedimentary rocks of Silurian, Devonian, and Ordovician age. These rocks extend across the north-trending Cincinnati Arch, crossing Ohio through Kentucky to Tennessee. The Jessamine Dome is a regional domal structure along the Cincinnati Arch in central Kentucky, and is reflected in the outcrop pattern of the Upper Ordovician units in the center of the map. Three major fault systems are also present in the Harrodsburg 30 x 60-minute quadrangle: the Lexington, Kentucky River, and Irvine–Paint Creek Fault Systems.

The individual 7.5-minute quadrangle maps (scale 1:24,000) were vectorized and attributed in Arc/Info from raster images of the stable-base Mylar composites, using a semi-automated data-capture technique. Compiling 32 individual 7.5-minute maps into a 30 x 60-minute map (scale 1;100,000) required resolving significant problems, such as (1) correlating geologic formations across quadrangle boundaries, (2) displaying nonuniform structure-contour horizons, and (3) resolving discrepancies in Quaternary alluvium boundaries and inferred contacts. Resolving the differences between quadrangles was necessary for topological analysis in a geographic information system (GIS). In addition, lithologic members mapped on the individual 7.5-minute quadrangle maps that were deemed too small to be mapped at a scale of 1:100,000 were mapped and consolidated with their adjoining members at the formation level.

A scaled schematic digital cross section was created in Arc/Info, using ARCPLOT's SURFACEXSECTION command on the grid lattices created from the available digital elevation models (DEM's) and the structure horizon grid created from the compiled structure contours. After the resultant two line sections were created, the structure-contour horizon was intersected with the DEM surface horizon, and the subsurface horizons were copied and pasted the appropriate distance below the surface during the editing process.

The final product consists primarily of an ArcView layout of the compiled formation polygon coverage, compiled fault and structure-contour arc and annotation coverages, economic point and arc coverages (quarries and mineral veins), city and town annotations, and associated coverages of digital line graphs (DLG's) of hydrology, roads, railroads, powerlines, pipelines, and county boundaries. Included on the final layout are a stratigraphic column, base maps, text, and the digital cross section. The final layout was created in ArcView on a 36 x 65 inch page layout and plotted on a Hewlett Packard DesignJet 755CM printer.

Different Needs, Different Bases: Struggling with Topographic Bases for Digital Geologic Maps

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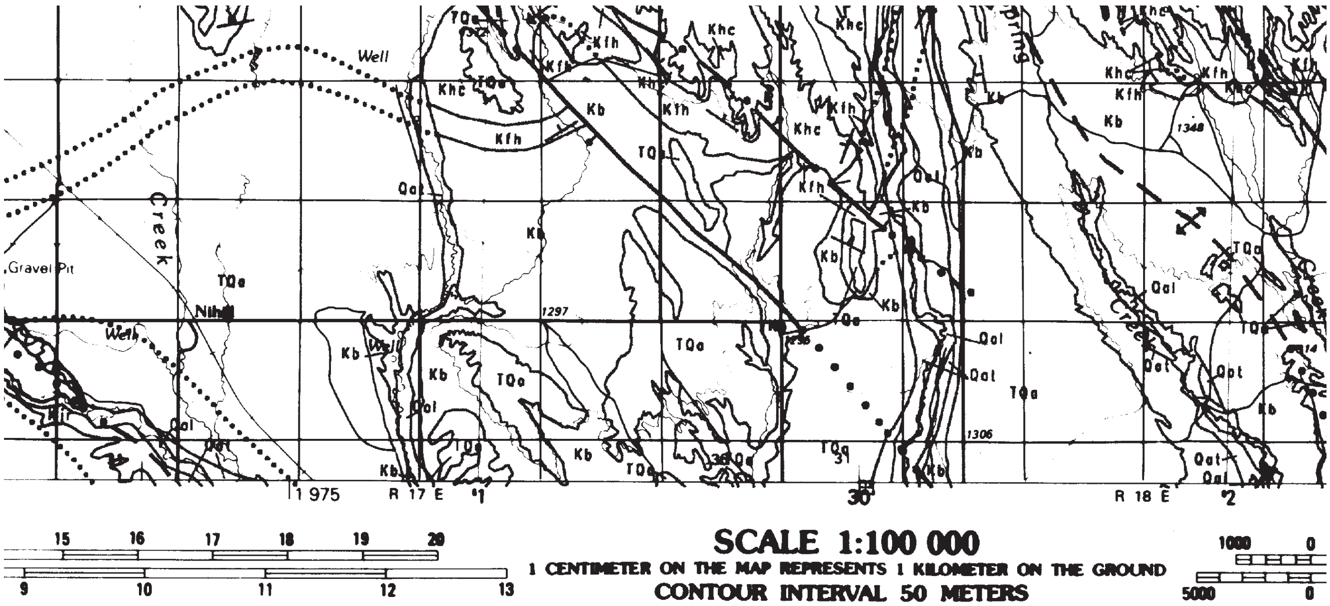
In the seven years that digital geologic maps have been constructed at the Montana Bureau of Mines and Geology (MBMG) using Arc/Info, a major problem has been providing base information that makes the maps more useful. Because of cost considerations, very few geologic maps are being produced by offset printing. In the past few years, most maps have been released as open-file reports. We are moving toward producing these, and possibly additional map series, as plot-on-demand digital products.

The current fundamental mapping scale at MBMG is 1:100,000. In the past few years, digital line-graph data of cultural features and water and digital public land survey system data became available at several mapping scales. However, the most important base feature for geologic maps is topography. To date, we have used three different techniques to add topographic data to digital geologic map products, each of which has associated advantages and problems: *(1) mechanical topographic contours*, *(2) raster topographic contours,* and *(3) digital hillshade relief.* The methods, problems, and successes of these different approaches are summarized below.

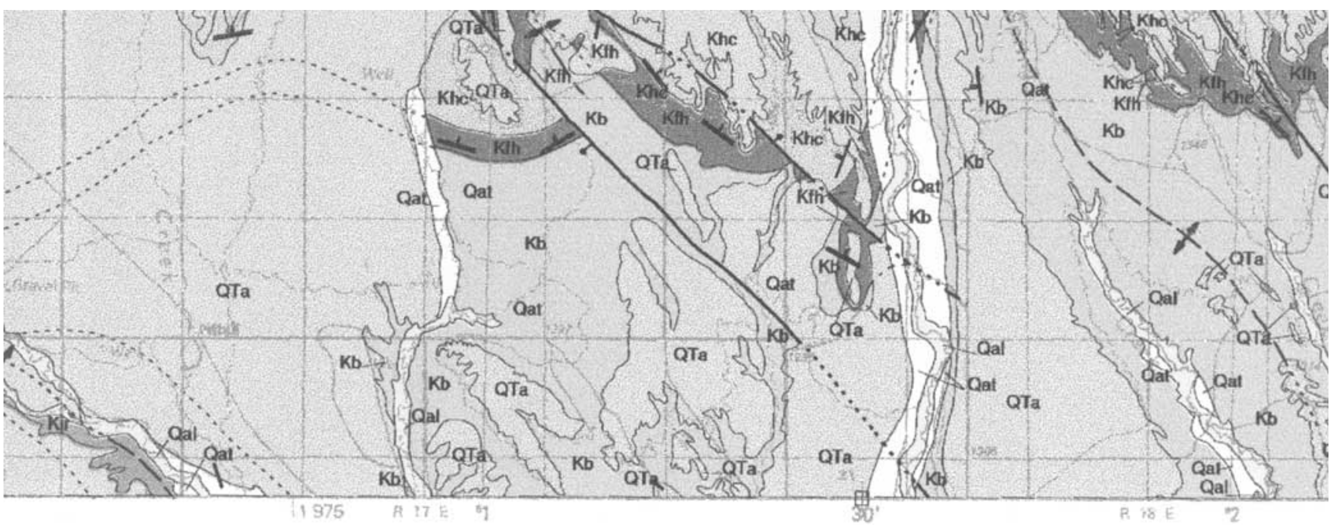
(1) Mechanical topographic contours: A blackline mylar plot of the geologic arcs and labels is overlain on a blackline mylar of a U.S. Geological Survey (USGS) topographic quadrangle to produce a sepia mylar from which diazo prints are made. This method is a holdover from our previous printing methods for production of open-file maps (Figure 1A). Major problems with this approach are: (a) having to use a large vacuum frame and separate light source rather than our roller-drive diazo print machine; (b) needing screened mylars of all topographic quadrangles; (c) the need for linework to be relatively heavy for adequate reproduction quality, and (d) the resulting lack of a colored product. We never fully carried out this procedure.

(2) Raster topographic contours: A raster representation of a USGS topographic quadrangle is acquired from a digital raster graphic (DRG) file or by in-house scanning (usually at 400 dpi) of a mylar of the USGS topographic quadrangle. The image is then layered with geologic data. The topographic data from DRG files need some processing to strip out some colors, change the colorizing scheme to shades of gray, and turn the white areas transparent. The raster data are rectified in Arc/Info, on our Unix system. Image processing is done on personal computers using Adobe Photoshop and Macromedia Freehand. Geologic data have been added with or without colored polygons. Our current approach is to overlay colored polygons with gray-scaled topographic data, and then put geologic arcs and annotations in black over the other layers, and to print the product on our 360 dpi inkjet plotter (Figure 1B). The main problems with the products are (a) the busyness of the maps where unit labels and other data are superimposed on base data, and (b) the lack of contrast between some polygon colors and the gray topographic base data. These color maps are more useful than maps with blackline geology on blackline topography of method (1), but lack some of the crispness and readability of maps produced with vector basemap data.

(3) Digital hillshade relief: A gray hillshade image produced from a digital elevation model (DEM) is combined with the geologic coverage to produce a shaded-relief geologic map. The hillshade is constructed in Arc/Info from available DEM's (mostly 30 m data with artifacts in western MT and three arc-second data in eastern MT). Filtering and vertical exaggeration of the elevation data are typically used. Topographic and geologic data are composited as grids, producing three grids in the



Map (A)



Map (B)

Figure 1. Examples of geologic maps produced by two methods of adding topographic data to geology layers. Contacts, faults, and axial traces of folds are shown by solid or dashed lines; concealed contacts, faults, and axial traces of folds are dotted. The grids are sections in the public land survey system.

Map (A) Example of a sepia mylar used to make diazo prints of Open-File Report, using method (1) to supply topographic contour and geologic data. Note that (a) the thick line weights required by the diazo print process make for poor definition between geologic and base data, and (b) the general busyness of the map.

Map (B) Gray-scale plot of a color print, made from a 360 dpi inkjet plotter, showing results of method (2). Gray-colored base data, on the original print, are on top of the colored polygons, but beneath the black arcs and annotations. Resolution of some of the base data is poor; some of the labels on the base are illegible. There is an overall decrease in the busyness of the linework in comparison to Map (A).

hue-saturation-value model, which allows for lightening or darkening of the image when a graphics file is created (Renaud, 1994). Where adequate DEM data are available (currently only in western MT), the products make visually striking displays that show geologic data in a highly understandable format. However, the lack of topographic contours hinders geologic applications that require quantitative elevation data.

Ideally, at a minimum we hope to print and provide digital versions of our geologic maps with contour bases; we hope also to provide hillshaded topographic bases, depending on the needs of the customer. Acquisition of raster topographic contour data that is legible at map scales is a surmountable problem; acquiring similar vector data is more of a problem. Method (2) will likely be used to produce our normal products. The enthusiastic reception we have received for geologic maps on shaded relief topographic bases encourages us to continue to produce these products.

REFERENCES

Renaud, 1994, Representing Color Spatial Data Over Monochrome Images: Proceedings of the Fourteenth Annual ESRI User Conference-May 1994.

Evolution of Digital Geologic Mapping at the North Dakota Geological Survey

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INTRODUCTION

The North Dakota Geological Survey (NDGS) is the primary source of geological information for the state of North Dakota. The NDGS was created in 1895 for the purpose of identifying and cataloging mineral resources within the state. Over the years this mission has been expanded and now includes three primary responsibilities: 1) investigate the geology of North Dakota; 2) act in an advisory capacity to other state agencies and administer regulatory programs; and 3) provide public service and information to the people of North Dakota. To fulfill these responsibilities, NDGS geologists conduct diverse studies of the state's surface and subsurface geology, publish the results in a variety of formats, and provide cooperative and outreach services to other government agencies, public groups, and interested individuals.

No single media has proven as effective as the geologic map in disseminating geologic information to geologic professionals and the general public. Geologic maps in one form or another have been included in nearly all NDGS publications, from the first Biennial Report in 1901 to our current STATEMAP projects. Over this period, mapping techniques and technologies have changed dramatically. NDGS geologists have increasingly been utilizing digital (ie. computerized) methods for map production in an effort to more efficiently and economically publish the results of our research.

HISTORY OF NDGS GIS CENTER

The NDGS took a lead role in geographic information system (GIS) development in North Dakota. A GIS refers to the computer software and hardware needed to input, store, analyze, and output geographic data. In a larger sense, the "system" also refers to the trained personnel, data, and organizational structure needed to effectively convey and use geographic data (Vonderohe, et al, 1991). The NDGS began developing its GIS in 1989 (Figure 1) after NDGS geologists were introduced to the technology at a national meeting. The NDGS created a strategy for assembling the necessary hardware and software components and entered into an agreement with the U.S. Environmental Protection Agency (EPA), State Department of Health and Consolidated Laboratories, and State Department of Agriculture to develop a GIS housed at the NDGS offices in Bismarck. The EPA provided the first hardware as an in-kind grant, including two Data General Unix workstations, two Laser printers, and one color printer. With the purchase of Arc/Info GIS software, the NDGS established its GIS Center in 1991. A SUN IPX workstation, a large scanner, a large digitizer, an additional copy of Arc/Info, and ArcView software were purchased in 1992, thereby increasing GIS capabilities. The NDGS also took responsibility in 1991 for creation and maintenance of the North Dakota GIS Spatial Data Clearinghouse. Most of North Dakota's digital spatial data is managed and distributed by the NDGS on the world wide web at <http://www.state.nd.us/ndgs/gis.html>.

Many of the first NDGS GIS projects produced maps from previously existing spatial data sets. Early GIS projects were a cooperative effort between the NDGS and other state agencies and included production of oil well location maps, endangered species maps (with the cooperation of the ND Game and Fish Department), and legislative districts map (with the cooperation of the Secretary of State's office). Geographic Information System Center

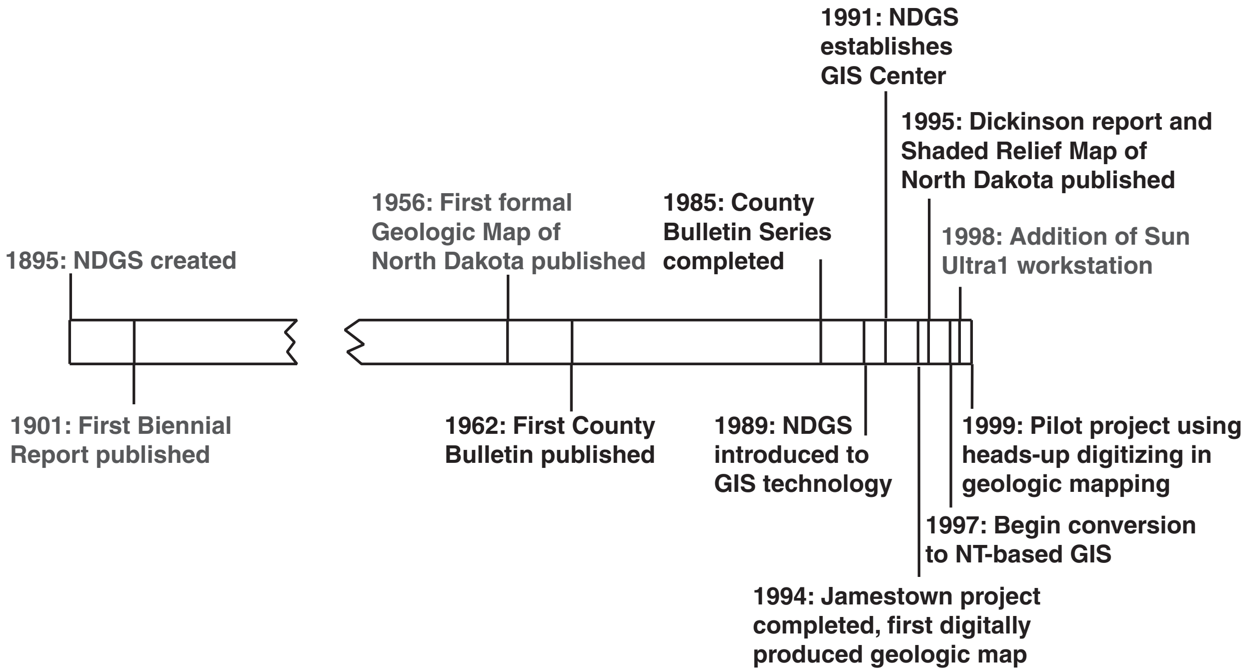

Figure 1. Timeline showing evolution of the geologic mapping program at the NDGS from the agency's creation in 1895. The mapping program has been undergoing rapid change since introduction of digital technology in 1989.

staff also made it a priority to convert existing geologic maps to a digital format. The first product to utilize the power of GIS modeling capabilities was the Shaded Relief of North Dakota map (Luther et al., 1995), created from digital elevation models from the Defense Mapping Agency (Figure 2).

Use of digital techniques spread to our active mapping programs, including STATEMAP projects. STATEMAP, a component of the National Cooperative Geologic Mapping Program, is a cooperative program providing USGS funding for geologic mapping completed by state geological surveys. The first NDGS STATEMAP project to use digital methods was the geologic mapping of the Jamestown, ND, area completed in 1994 (Biek, 1994). Three 7.5 minute quadrangles were mapped at a scale of 1:24,000. Unfortunately, the project was hampered by the lack of digital base data available at that scale. Base data, like U.S. Geological Survey digital line graphs, were available only at a scale of 1:100,000 for most areas of North Dakota at that time and only one of the three quadrangles had an existing 1:24,000 digital base. The next STATEMAP project, geologic mapping of four 7.5 minute quadrangles in the Dickinson, ND, area, was completed in 1995 (Biek and Murphy, 1995). The Dickinson project was the first NDGS mapping project to use digital techniques for final preparation of all map products.

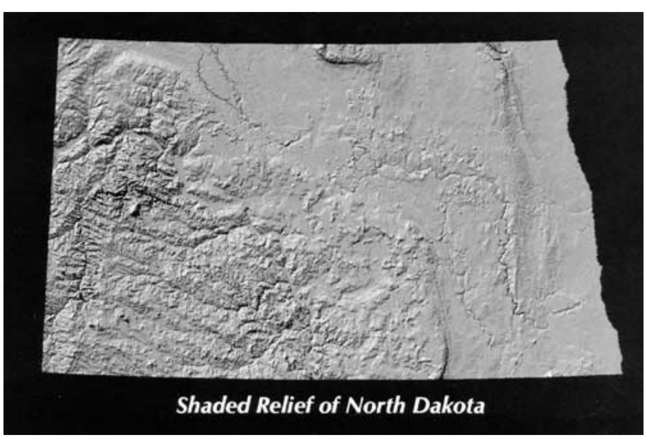

Figure 2. Shaded relief map of North Dakota. This map, published as NDGS Miscellaneous Map 32 (Luther et al., 1995), was the first NDGS product to utilize the modeling capabilities of GIS.

MAP PRODUCTION PROCEDURES

Geologic mapping projects completed since the GIS Center was established have utilized an approach which combines both manual and digital techniques. The procedure has changed little since the NDGS began digital map production back in 1991. Field data are compiled on a conventional paper base map and interpreted to produce a draft geologic map. The geologic features are then drafted in ink onto a mylar positive of the base map and the inked geologic information is digitized in Arc/Info using a digitizing tablet. Features are attributed and coded to create the final digital geologic map. After review by a cartographer and the mapping geologist, the digital map is ready for release.

Final maps are available to the public as either a stand-alone, print-on-demand (POD) product or as part of a NDGS publication. The maps produced recently from STATEMAP projects have been published as open-file reports and have been printed for customers on demand. The maps are also available as digital data files upon customer request.

FUTURE MAP PRODUCTION PROCEDURES

The NDGS digital mapping program continues to evolve as new technologies and techniques become available. Desktop GIS software packages with increasing functionality and "heads-up digitizing" are an example of the new technology. In heads-up digitizing, the mapping geologist transfers field data from their field maps directly into a digital format using a desktop (or workstation) GIS software package. The NDGS recently received STATEMAP funding to begin a new geologic mapping/compilation project in northeastern North Dakota in which we intend to use ArcView v. 3.1 to enter geologic field data directly from our field maps using U.S. Geological Survey Digital Raster Graphics as a base layer. Our approach is based on that used by the Missouri Division of Geology and Land Survey (Starbuck, 1998). Heads-up digitizing eliminates the intermediate drafting and digitizing steps and should eliminate error introduced during those processes. We hope this technique will also eventually improve map-production efficiency by reducing the amount of time spent editing and reviewing the maps prior to publication.

DISCUSSION

Our shift to heads-up digitizing, desktop GIS, and POD products is in response to increased demand for digital map products and the increased number of maps we wish to publish within a limited publications budget. We must face numerous issues as the NDGS GIS Center evolves, including stability of our POD products, metadata and "version control" as we move towards greater use of desktop GIS, standardizing of map units and colors, and increasing quality within the limitations of our budget.

Stability

The greatest advantage of the POD map production process is that POD is a relatively inexpensive way to provide information to the public. In addition, storage space in our publications and map sales area is saved because of reduced inventory. Disadvantages to our current POD process include unstable media, increased waiting time for customers, and decreased quality. Currently we use a Hewlett Packard DesignJet 2000CP with standard ink jet paper. Printing sometimes takes 15 minutes or more and customers have to wait for their map to spool, print, and dry. The ink fades significantly in a relatively short time, especially if displayed in direct sunlight. The ink also has a tendency to rub off with handling and is destroyed by moisture, thereby decreasing the quality of the printout. Stability and quality can be improved by using a coated or glossy paper designed for printing high quality products. However, using a more expensive paper results in somewhat higher POD cost.

Metadata Standards and "Version Control"

The GIS Center staff recently began using a standard metadata template when constructing a new digital data set. Metadata are the documentation about the reliability and quality of the source(s) of information used to create a data set. The NDGS metadata template is based on the USGS template and complies with Federal Geographic Data Committee (FGDC) standards. Due to limited staff resources, earlier data sets were not documented with formal metadata. In some cases, little information is available to reconstruct complete metadata documents. We collect as much information as possible in these cases, and release them as "User Beware" data sets.

Use of GIS mapping techniques allows a user to quickly and easily update or change an existing data set. Although this is appealing, this speed and ease of changing data sets can also be troubling for the GIS manager, especially with increased usage of desktop GIS. At the NDGS, the most current version of a data set is stored in the GIS Center workstation, and all requests for digital information, either internal or external, must be made through the GIS manager. It is the GIS Manager's responsibility to fill that request and make sure that the user has the most current version of the data set. The data is transferred via internal network, File-Transfer-Protocol, or a copy of the file is made to CD-R or floppy disk. Desktop GIS users have the responsibility to inform the GIS manager of any changes they make to the coverages. It is hoped that this method will avoid possible duplication or accidental deletion of data sets.

Standard Map Units and Colors

We are fortunate that the geology of the entire state of North Dakota has been mapped at a reconnaissance scale of 1:125,000. The original maps were produced as part of the County Bulletin series, a cooperative effort between the NDGS, ND State Water Commission, and the U.S. Geological Survey, that took 14 geologists 23 years to complete. However, the reconnaissance maps use a different color scheme for different counties and often use different geologic names for similar geologic units. These variations in colors and units were necessary adaptations to our evolving understanding of North Dakota geology and reflect the growth of geologic knowledge, not any inadequacy of the mapping system. However, they do pose a challenge to our digital conversion efforts.

The NDGS has never established standard geologic map units and colors for geologic studies in North Dakota. Currently, three geologists on our staff are working on STATEMAP-funded projects. Each geologist creates a legend that is appropriate for the area in the state they are mapping and for potential users of the map. This lack of standardization creates problems when merging adjacent quadrangles mapped by different workers. The GIS manager, in consultation with the geologists, must reconcile the differences between the adjacent quadrangles. This is often a time-consuming process that should be avoided whenever practical.

FUTURE GOALS FOR NDGS GIS CENTER

The NDGS GIS Center will continue to evolve and grow as we expand our use of digital techniques and acquire new technology to improve our products. We have identified seven goals to help us keep pace with this rapidly growing industry. Some of these goals address the shortcomings of our existing digital mapping program. Others are intended to enhance our programs and offer additional products and services to our customers.

1. Explore printing techniques and materials to produce higher quality print-on-demand products.

If we are to continue to produce most new geologic map products as POD publications, we need to find economical ways to improve the quality and stability of these products. Their usefulness is presently limited by their lack of durability.

2. Develop and maintain metadata for all NDGS digital data sets.

Metadata need to be compiled for all existing NDGS data sets. We will continue to adhere to our standard metadata template for newly created data sets and revise this template as necessary to maintain FGDC compliance.

3. Standardize map units and colors.

The GIS Manager continues to stress the importance of standardized map unit names and colors. The geologists continue to resist standardization and deal with edge-matching problems on a case by case basis. The mapping geologists do make every attempt to reconcile their new map with adjacent, preexisting maps. However, each geologist brings their own unique perspective to interpreting field observations. They prefer to create objectively defined units that suit the particular mapping application, rather than pigeon-holing their observations into a predetermined standard.

4. Digitize all out-of-print maps and place them on the world wide web.

In the past, a number of customers have requested out-of-print maps. Currently, the best we can do is to refer them to the NDGS Library, the State Library, or a university library. As the use of digital data becomes more common, having out-of-print maps in digital format will be beneficial to not only our own agency, but also to other agencies, such as the State Health Department, State Historical Society, ND Game and Fish Department, and State Water Commission.

5. Explore combined capabilities of GIS and stratigraphic software packages (Petra™).

The NDGS recently purchased Petra™, an integrated database and stratigraphic software program. The full potential of this new software package combined with GIS software is yet to be explored at the NDGS. There are great potential benefits to all aspects of our research, including petroleum exploration, oil and gas reservoir estimates, geologic mapping, lignite reserve estimates, and other economic geology applications.

6. Hire an IT/GIS Analyst.

An additional person with training and extensive experience in computer networking, database management, and GIS management is necessary for the continued successful operation of the NDGS GIS Center. Currently, general computer maintenance is performed by an NDGS geologist who happens to be very interested and knowledgeable about computers. Computer maintenance costs could be substantially reduced by hiring an IT/GIS analyst to take over these duties from a staff geologist. The NDGS has requested funding for this position, but at the time of this writing, it remains to be seen if funding will be approved by the state legislature.

7. Decrease turnaround time for map products.

With the addition of GIS staff and the use of ArcView, it is hoped that turnaround time for map production will be reduced. This will enable us to quickly produce maps dealing with time-sensitive issues, like flooding or land-use changes, and make our agency's products more visible to the public and legislators.

CONCLUSION

The use of digital mapping techniques at the NDGS has greatly enhanced our mapping capabilities. Digital methods allow us to produce print-on-demand map products that can be updated as new data become available or customized to serve a specific user need. This flexibility enables us to better serve our customers, whether they are trained geologists, engineers, land-use planners, or the general public. However, there is always room to improve. We recognize the problems in our current approach, particularly with regard to product stability and standardization. New technologies continually become available to simplify or streamline digital processes, new applications of digital mapping are created, and new methods of integrating diverse data are constantly being developed. We hope that, by critically examining our current system and participating in events like this Workshop on Digital Mapping Techniques, we can direct our growth to make the best use of limited resources while maintaining our high quality standards.

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The Integration of Sinkhole Data and Geographic Information Systems: An Application Using ArcView 3.1

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The Pennsylvania Geological Survey initiated the sinkhole inventory project in 1985 to systematically map karst features on a county-wide basis. Each hard-copy county report includes a brief explanatory text and copies of 7.5 minute quadrangle maps (scale 1:24,000) that show the locations of sinkholes, surface depressions, surface mines, cave entrances, and carbonate bedrock geology. Fourteen counties have been surveyed in detail and six others have had a less detailed, reconnaissance survey completed.

The PC-based GIS software ArcView v. 3.1 is being used to analyze the data. Themes are created to include: a digital raster graphics (DRG) 7.5 minute topographic base map, a digital geologic base, geo-referenced karst data, and a box-style grid with grid cell spacings set at 500 feet to cover the 7.5 minute base map. Using sum and join functions, each unit cell containing karst point data is identified, the number of features contained within the unit cell is counted, and a color that corresponds to a particular range of numbers is assigned to that unit cell. The end product is a color-coded map that shows the density of karst surface features over a given area. The distribution of these features becomes visually apparent by showing high-density (bad) areas and low-density (good) areas. By using the identify function, additional information about a particular point can be obtained.

This customized data can be utilized for a variety of projects ranging from permit applications to land-use planning to spatial analysis.

The Making of the 1:250,000-Scale Digital Geologic Map of Pennsylvania

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In 1980, the Pennsylvania Geological Survey (PaGS) published a new edition of Map 1, *Geologic Map of Pennsylvania*. This full-color map, which was compiled and printed at 1:250,000 scale, shows the areal distribution and extent of the bedrock geologic units in Pennsylvania. Since its publication, Map 1 has remained the most current, available source of bedrock geology for the entire state and has had widespread use for regional studies. The increasing use of GIS technology in the past five years has led to numerous requests from federal and state government agencies and the private sector for a digital version of the map. In response to these requests, the PaGS has converted the geologic features depicted on Map 1 to a digital format. Two data sets were prepared using ARC/INFO software, one for geologic units and faults, and the other for dikes. The data sets contain 194 geologic units, more than 12,000 polygons, and more than 30,000 arcs.

Production of the data sets involved preparation of scanned images of the 1:250,000-scale geologic units and faults from the 1980 map. Because of inherent problems with the 1:250,000-scale base map, scans were also made of the source materials that were used to compile the state geologic map in order to more accurately locate the geologic contacts in relation to streams, roads, and other base features. The images were georeferenced and projected to transverse mercator, the projection of the 1980 map. Vector files were edited on screen on a computer workstation with the images in the background for reference.

In compiling the data set for the geologic units, the PaGS extensively modified an earlier data set of geologic formational contacts prepared by the U.S. Geological Survey, Water Resources Division. The PaGS edited or redigitized all arcs, relocated and corrected polygon label points, digitized all fault lines, and added several items to the polygon and arc attribute tables. Polygon attributes include map symbol, name of geologic unit, age, and three lithology designations. Arc attributes include type of geologic contact line, fault line, and boundary line. The data set for dikes was prepared entirely by the PaGS and contains only line attributes: map symbol, name, age, lithology, and the type of dike line. The accuracy of the attributes and positioning of the arcs and polygons were checked by preparing and proofreading numerous check plots, verifying the data on screen, and preparing a script in Arc Macro Language to ensure correctness of polygon attributes.

It is anticipated that the data sets will be of use for a variety of regional or statewide GIS applications, including water-resource and environmental studies, land use planning, conservation and ecosystem management, mineral exploration, and industrial development.

The Development of a Digital Surface and Subsurface Geologic Map Database of Charleston County, South Carolina

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HISTORY OF GEOLOGIC MAPPING IN REGION

Since 1974, the USGS has conducted geological investigations relating to the tectonic and earthquake history of the Charleston, SC region. Earlier studies, such as Rankin (1977) and Gohn (1983), were a combination of geophysical, tectonic, and seismic investigations. Near–surface, and surface geologic maps were published by Force (1978a, b) and McCartan and others (1980). Mapping of the region at a small scale was completed by McCartan, Lemon, and Weems (1984), and subsequent mapping efforts by Weems and Lemon provided a more detailed coverage of the Charleston area at 1:24,000 scale (Weems and Lemon, 1984a, b, 1987,1988, 1989, 1993, 1996, Weems, Lemon, and Chirico, 1997). Weems has continued mapping surficial and near-surface formations in and adjacent to Charleston County and it is this latest effort which has included the advent of digital geologic mapping in the region.

SOUTH CAROLINA COASTAL PLAIN/CHARLESTON COUNTY PROJECT

The goal of the project is to develop a comprehensive large-scale, digital geologic dataset of surface and near-surface geology and a smaller scale subsurface geologic coverage for the Charleston county region. Thus the mapping project was divided into two sections. The first was the conversion and continued development of a large-scale surface geologic database for the area. The second was a subsurface stratigraphic framework for the same region.

SURFICIAL GEOLOGY DATABASE DEVELOPMENT

The large-scale surficial and near surface mapping project consisted of three types of map development. First, seven printed maps of Charleston County 7.5 minute quadrangles were converted into a geographic information system (GIS) database. Second, all new mapping in the region was compiled on mylar separates for the development of new digital databases. Third, several datasets previously compiled but unpublished, consisting of hand drafted linework on greenline quadrangles, needed to be converted to digital format. Although the same process was employed for all types of data conversion, printed versions and unpublished compilations, the GIS staff experienced different challenges during the conversion steps.

The GIS staff employed a method of scanning, vectorizing, editing, and attributing for digital database creation. Although the process was basically the same for previously published maps, unpublished compiled greenlines, and new mapping compilations, the differences in the original medium required differences in methodology. Previously published maps, which had map separates available, were easily scanned and compiled, whereas greenlines of unpublished data were more difficult to work with.

Scans that were made directly from hand drafted compilations of greenline quadrangles contained written text leader lines and other extraneous information that produced complex linework, much of which required deletion (Figure 1a). For new mapping, geologists drafted on mylar that was overlayed on plotted digital basemap files (Figure 1b). These digital basemap files were updated datasets of topographic features and are available in

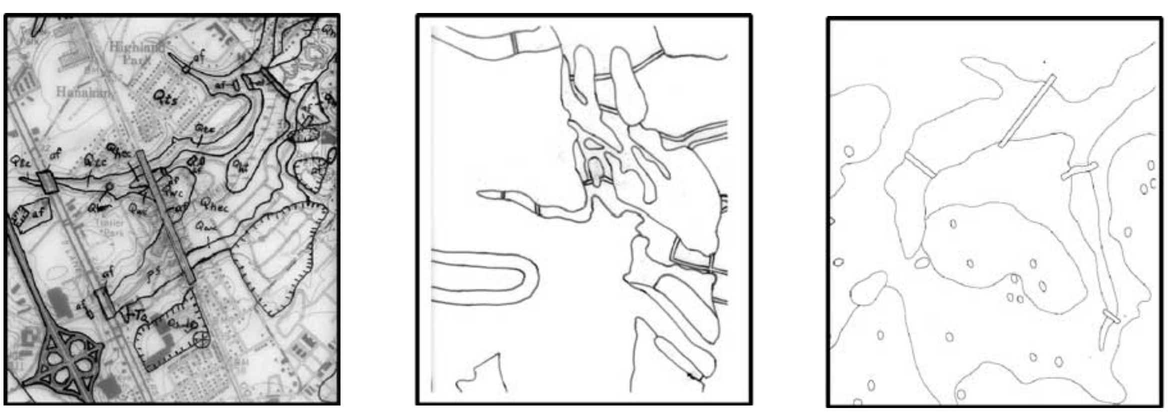
Arc/Info format through the South Carolina Department of Natural Resources, Colombia, South Carolina at <http://water.dnr.state.sc.us/gisdata/index.html>. In the case of published maps, photographic reproductions of linework were procured for scanning. These black-line positives of scribed linework were ordered from Eastern Region Publications Group of the USGS where some of the scribed map separates still reside. Scans derived from this medium were clean and contained only geologic contact information (Figure 1c).

The scanning process utilized an Anatech Eagle 4080 ET large-format scanner, capable of scanning documents up to 40 inches in width. Separates, blackline, and mylar overlays were scanned at different resolutions to provide the best possible file for the vectorization step. Blackline positives are scanned at higher resolutions, between 600 and 800 dots per inch (dpi). Hand drafted greenlines and mylar overlays generally were scanned at 400 dpi. The threshold setting on the scanner regulates the amount of light passing through the medium and therefore affects the clarity of the resulting scan. This threshold setting was altered for each type of media to produce the best possible raster image for vectorization. Blackline positives were scanned using a threshold of approximately 160–180, whereas the hand drafted media needed a higher threshold (190–210) to eliminate some background noise and produce cleaner lines. The raster scans were stored in .tiff or .rlc file format. These raster data formats are accepted by the GTX-OSR (GTX Corporation - Phoenix, Arizona) vectorizing software.

Vectorization of the scanned raster data was a straightforward process and resulting output files of vector linework were saved as Drawing Exchange Format (.dxf) files. Dxf files are easily imported into Arc/Info where the editing process occurs. The editing of vector linework to build topologically correct datasets of geologic polygons and lines was the most important and time comsuming step. Vector linework was projected into the same coordinate system as the digital basemap files (UTM 17, NAD 1927).

Digital basemap files of hydrography and hypsography as well as roads and miscellaneous transportation were downloaded and used as boss layers or backcoverages (drawn on screen in background during the digital editing phase) for the digital compilation. The digital basemap files of hydrography were of particular importance as boss layers for compiling surficial geologic maps because hydrographic and topographic features such as marshes, swamps, mudflats, and islands needed to be copied directly into the new digital geologic coverage. This was done to ensure that geologic and hydrologic features would coincide exactly on future plotted copies and for any subsequent GIS analysis. Hypsography (topographic contour lines) was used in a similar manner. Instead of directly copying lines however, geologic contacts were edited to follow hypsographic lines where required by geologic conditions. For example, geologic contacts describing alluvium and artificial fill were edited to follow the appropriate lines of the topographic backcoverage.

Because the utility of having geologic data in a digital format is the ability to view, query, and analyze the data, a database was developed separately and included a variety of qualitative information that might be useful to data users. A simple database was constructed in Microsoft Access for each of the units depicted on the map. This database was saved as a .dbf file. The .dbf file format was converted into an Arc/Info database file or .info file



A *B* *C*

Figure 1. Examples of three different geologic data mediums that were digitized. ***A.*** Greenline with hand drafted data. ***B.*** New hand drafted mylar overlay. ***C.*** Black-line positive map separate.

through the dbaseinfo command. The .info file was then joined to the spatial database with the joinitem command. An explanation of those database items is contained in Appendix 1. An example of the database for surficial geologic map units follows:

AREA	=	9504.188
PERIMETER	=	376.169
CHAR_GEOL#	=	6
CHAR_GEOL-ID	=	730
MAP_UNIT	=	Qwc
ID	=	9
UNIT	=	Wando Formation
FACIES	=	clayey sand and clay
DEPO_ENV	=	backbarrier (estuarine/lagoonal)
RELATIVE_AGE	=	late Pleistocene
MIN_AGE	=	90000.00
MAX_AGE	=	110000.00
ABSOLUTE_AGE	=	90-110 ka
LITHOLOGY	=	silt
MODIFIER_1	=	clayey
MODIFIER_2	=	sandy
MODIFIER_3	=	very fine-medium
MODIFIER_4	=	bioturbated
FRESHCOL1	=	pale-yellowish-orange
FRESHCOL2	=	medium-light-gray
WEATH_COL1	=	grayish-yellow
WEATH_COL2	=	dark-yellowish-orange
COMPACTION	=	moderate

The final digital databases are stored in an Arc/Info format but are commonly displayed and distributed in an ArcView project. Figure 2 illustrates the combined set of 7.5 minute quadrangles for the northeastern part of Charleston County, South Carolina.

SUBSURFACE GEOLOGIC DATABASE DEVELOPMENT

The subsurface geologic dataset is a collection of auger holes, water wells, and core holes drilled and logged throughout the South Carolina coastal plain. A preliminary dataset of only the Charleston County subsurface data layers was completed to demonstrate the organization of the data.

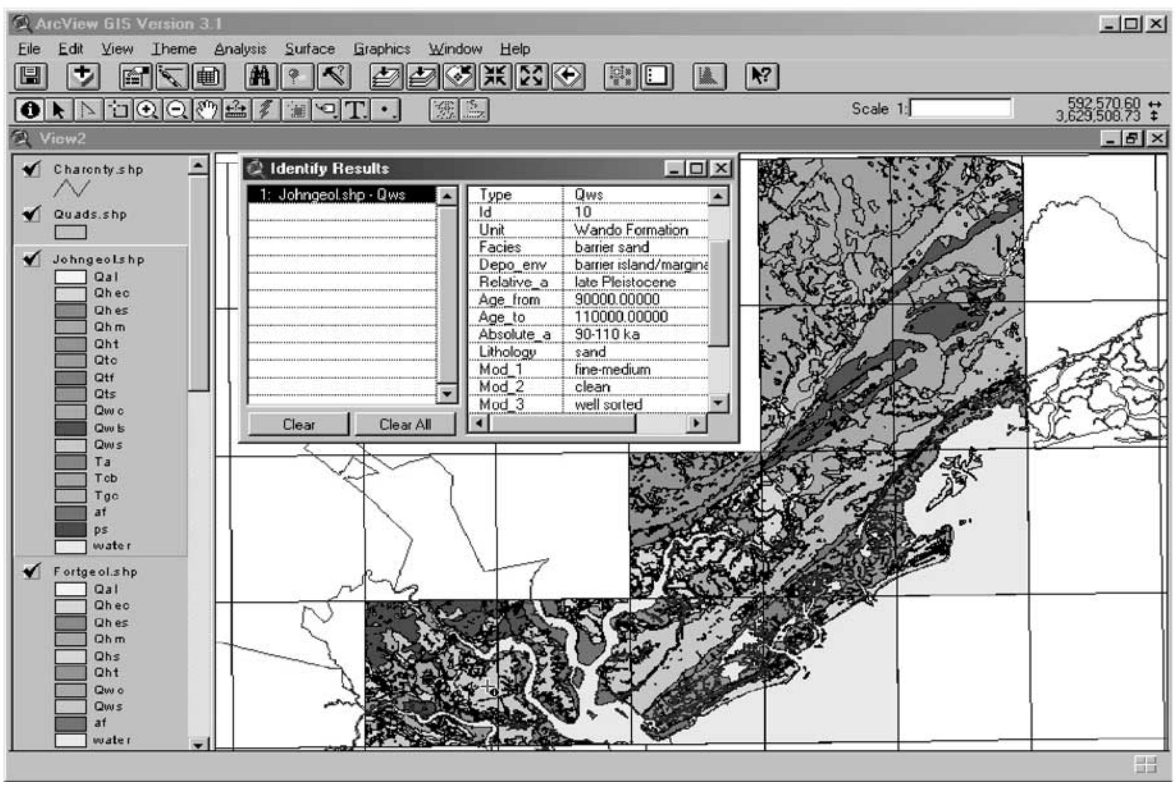


Figure 2. Surficial geologic maps in an ArcView project.

This database was developed for six units from the Maastrichtian to the middle Eocene age.

Data for each corehole includes gamma and electric logs, and lithologic and fossil data. Geologic formations are recognized at different depths throughout the core by analyzing the available data. Depths to each geologic formation are entered into an Access database for each core analyzed. Structure contour maps of any surface can then be prepared through contouring the data for a particular formation. The database is stored in a relational format to prevent duplication of information and to simplify the process of contouring surfaces of selected geologic units. The main data table stores identifier information for each core hole, and examples are shown in Table 1.

Ancillary data tables are linked to this identifier table through a common field (USGS_NO) and contain numerical values that show the depth to the top and bottom of the unit and each unit's thickness (Table 2). Several tables are created for each hole, each for a different geologic formation encountered at a different depth in that hole.

Contour maps were developed for the subsurface geologic units using Arc/Info ver. 7.1.1. Structure contour maps of the top and bottom of each unit as well as an isopach map showing unit thickness were developed. These contour maps were then stored as ArcView shapefiles. The collection of these subsurface layers was stored in ArcView GIS for the traditional two dimensional display structure contour maps. Additional work was then done to include several cross sections to illustrate the regions stratigraphy. Originally these cross sections were created in Micrographix Designer as .dxf files. The .DXF files were then opened in an ArcView View to be displayed (Figure 3).

FUTURE RESEARCH

With the acquisition of better desktop tools for presentation of complex subsurface datasets, the project scientists hope to better communicate this information to the public through visualization software. ArcView's 3D Analyst allows limited capabilities to show subsurface geologic units and their location with respect to the surface.

Future research and development in the use and applications of digital geologic maps will be an important step in the future of digital geologic mapping. Further studies with this dataset include designing maps to include pertinent quantitative data suitable for GIS analysis. Examples for surfical databases include detailed grain size information correlated across geologic units, and blow count or density data for geologic units for some general measure

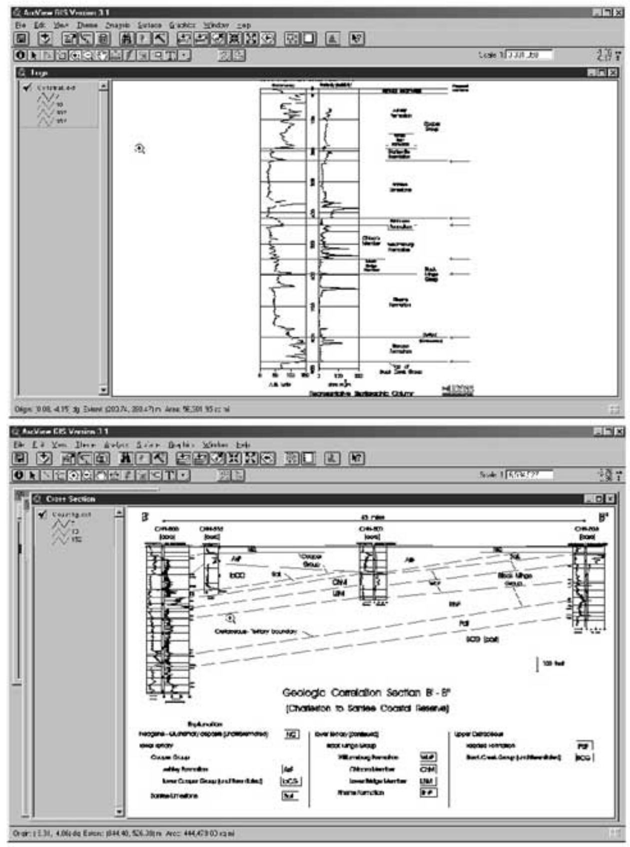


Figure 3. Geophysical logs and cross sections are stored as .dxf files in ArcView database.

Table 1. Example of the main data table for subsurface geologic information.

USGS_NO	SCWRC_NO	NAME	COUNTY	LATITUDE	LONGITUDE	TOTALDEPTH
CHN_635	16DD-y3	Town of Sullivans Island	Charleston	32.76444	79.83278	2540.00000
DOR-37	23CC-I1	USGS-Clubhouse Crossroads #1	Dorchester	32.88806	80.35917	2599.00000

Table 2. Example of ancillary data tables containing information for a particular geologic formation

USGS_NO	DATUM_ELEV	DEPTH_TOP	ELEV_TOP	DEPTH_BASE	ELEV_BASE	THICKNESS
BRK-089	32.00000	328.00000	-296.00000	490.00000	-458.00000	162.00000
BRK-272	18.00000	541.00000	-523.00000	678.00000	-660.00000	137.00000
CHN-011	10.00000	749.00000	-739.00000	836.00000	-826.00000	87.00000
CHN-012	10.00000	752.00000	-742.00000	845.00000	-835.00000	93.00000

of strength. Geologic map databases must be prepared to address problems of cooperating agencies. In Charleston County, issues ranging from coastal erosion and storm surges, land use planning for growing coastal communities, groundwater resource issues, and further studies related to earthquake hazard and liquefaction potential all require geologic map data to produce viable derivative products.

APPENDIX 1. ARC/INFO DATABASE DESCRIPTION

Data Format of Database

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC
1	AREA	4	12	F	3
5	PERIMETER	4	12	F	3
9	CHAR_GEOL#	4	5	B	-
13	CHAR_GEOL-ID	4	5	B	-
17	TYPE	5	5	C	-
22	ID	8	11	F	0
30	UNIT	30	30	C	-
60	FACIES	30	30	C	-
90	DEPO_ENV	40	40	C	-
130	RELATIVE_A	25	25	C	-
155	MIN_AGE	8	20	F	5
163	MAX_AGE	8	20	F	5
171	ABSOLUTE_A	15	15	C	-
186	LITHOLOGY	15	15	C	-
201	MOD_1	20	20	C	-
221	MOD_2	20	20	C	-
241	MOD_3	20	20	C	-
261	MOD_4	20	20	C	-
281	FRESHCOL1	25	25	C	-
306	FRESHCOL2	25	25	C	-
331	WEA_COL1	25	25	C	-
356	WEA_COL2	25	25	C	-
381	COMPACTION	15	15	C	-

Definitions of Fields

TYPE: These unique designations are the geologic map symbols used for the various geologic units. The upper-case letters refer to the general geologic ages of the units (Q=Quaternary, T=Tertiary). The lower case letters refer to the name, specific age, and (or) facies of the geologic units (for example, Qhs=Quaternary+Holocene+barrier sands; Qwf=Quaternary+Wando Formation+fossiliferous shelf sand).

ID: Consecutively numbered units.

UNIT: Names of geologic units. Names with upper-case letters are formally defined (for example, Wando Formation). Units with names using lower-case letters are informally defined (for example,Ten Mile Hill beds, artificial fill).

FACIES: General statement of the depositional environment and (or) lithology of a geologic unit. FACIES represents the appearance and characteristics of a sedimentary unit, typically reflecting the conditions of its origin.

DEPOSITIONAL ENVIRONMENT: Describes the environment in which the sediments originally accumulated (for example, estuary,barrier island, marine shelf).

RELATIVE AGE: Age of the geologic units as identified on the standard geologic time scale. Defined in terms relative to other geologic units rather than in terms of years.

MIN_AGE: Numeric field containing the approximate minimum ages of geologic units in thousands of years. This field incorporates the minimum age range from the Absolute Age field but in a numeric form.

MAX_AGE: Numeric field containing the approximate maximum ages of geologic units in thousands of years. This field incorporates the maximum age range from the Absolute Age field but in a numeric form.

ABSOLUTE AGE: Ranges or values for approximate ages of geologic units as determined from fossil ages, amino-acid racemization ages, and (or) radiocarbon ages (ka=thousands of years, Ma=millions of years).

LITHOLOGY: The physical characteristics of rocks or sediments as seen in outcrops, hand samples, or subsurface samples. Described on the basis of characteristics such as color, mineralogic composition, and grain size. Principal sediment types found in the geologic units. Sands consist primarily of quartz grains between 0.0625 mm and 2.0 mm. Silts consist primarily of quartz grains between 0.0039 mm and 0.0625 mm. Limestone/marl deposits consist of true limestone or limy clay (marl). Muck consists of variable percentages of sand, silt, and clay mixed with a high percentage of fine-grained organic material. Descriptions of sediments in the LITHOLOGY and MODIFIER sections are qualitative visual descriptions.

MODIFIER 1, 2, 3, 4: These descriptive terms modify the principal lithologic terms. They are listed in a hierarchical order according to predominant characteristics. Modifiers may refer to size of sand grains (for example, fine-medium), to admixtures of materials of contrasting grain size (for example, silty, sandy, clayey), to special components (for example, fossiliferous, phosphatic), to grain-size sorting (for example, well-sorted, clean), or to stratification type or other fabric characteristics (cross-bedded, bioturbated).

Standard Geologic Grain Size Chart:
- Gravel: larger than 2.0 millimeters
- Sand:
  - Very coarse: 1.0 to 2.0 mm
  - Coarse: 0.50 to 1.0 mm
  - Medium: 0.25 mm to 0.50 mm
  - Fine: 0.125 mm to 0.25 mm
  - Very fine: 0.0625 mm to 0.125 mm
- Silt: 0.0039 mm to 0.0625 mm
- Clay: smaller than 0.0039 mm

FRESH COLOR 1, 2: Dominant (1) and secondary (2) colors of sediments in fresh exposures and subsurface samples. Color identification was visually determined in the field from the Geological Society of Americas standard color chart.

WEATHERED COLOR 1, 2: Dominant (1) and secondary (2) colors of sediments in weathered exposures. Color identification was visually determined in the field from the Geological Society of Americas standard color chart.

COMPACTION: Qualitative field assessments of sediment compaction stated as "loose", "moderate", or "dense". Younger sediments (Pleistocene and Holocene) tend to be loose or moderately compacted. Older Eocene, Oligocene, and Miocene sediments tend to be dense relative to the younger deposits but still may be penetrated with a knife blade using moderate pressure. (Weems and others 1997).

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Using Regions and Route Systems to Model Compound Objects in Arc/Info

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In many common geographic information systems (GIS), real-world objects are represented as points, lines, or polygons. The spatial representation of the object (i.e., the point, line, or polygon), in turn is often associated with tabular data. In Arc/Info, points, lines, and polygons are referred to as features and are stored in coverages (thematic data layers). Tabular data pertaining to these features is stored in feature attribute tables.

The mathematical procedure for representing geometry and spatial relationships of these features is called topology. According to *Understanding GIS: The Arc/Info Method* (Environmental Systems Research Institute, Inc., 1997), the three major topological concepts are 1) lines (arcs) are connected at nodes, 2) arcs that connect to surround an area define a polygon, and 3) arcs have direction and left and right sides.

Certainly, topology based on points, lines, and polygons adequately represents many geologic features, especially if those features represent single observations. For example, a sample location may be represented by a point, or an outcrop location by a point or polygon. However, many geologic objects are not easily represented by a single feature. This is further complicated by the mechanics of the topological data structure, which often undesirably fragment lines and polygons by placing nodes at line intersections. Consider two cases. In the first example, a single fault is offset by an intersecting fault, creating two individual line segments. In the second example, a bedrock geologic map shows multiple locations where a sedimentary unit has been eroded to reveal an underlying volcanic unit. Although the mapping geologist may have interpreted the fault segments as part of one system or the individual volcanic unit polygons to be part of a continuous unit at depth, this interpretation is obscured by fragmentation by the software. Although the attribute tables usually reflect this information, the visual integrity of the unit is compromised. Further, database size is negatively impacted, since individual entities have their own records in the feature attribute table. Does this system adequately represent our knowledge of the known geology? Or are there tools that can help us both maintain the geologist's interpretation of the data and minimize storage requirements?

Arc/Info provides two other feature types often overlooked by the geologic community: regions (which are based on polygons) and routes (which are based on lines). Essentially, regions and route systems aggregate overlapping, noncontiguous, and nested features, allowing the user to model them as singular entities. There is no limitation on the number of regions or routes that can exist within a coverage. When a region or route is initially created, a subclass name is assigned. Each region or route subclass then has its own feature attribute table. Further, region or route subclasses can be aggregated into larger region and route systems. It is important to note that the addition of these features types does not take away the geologist's ability to attribute individual entities. Individual polygons can still be attributed in the polygon attribute table. Route systems are even more flexible, allowing the user to attribute individual sections within a route.

If the volcanic unit discussed above was incorporated into a region subclass, the database user would better understand how the field geologist viewed the unit: as multiple occurrences of a single unit. In addition, the database size would be minimized as the attributes pertaining to each individual polygon are consolidated into one. Similarly, it may be advantageous to construct route systems with thrust, normal, and strike-slip subclasses. That way, individual faults of each type can be placed in their respective subclass without losing the ability to attribute individual fault segments.

In conclusion, regions and route have a wealth of applications in geologic data modeling. Although I have provided two cases of how they may be applied, their inherently hierarchical nature raises many implementation questions. Certainly, it is not advantageous to implement them in every case where lines or polygons share attributes. How extensively should they be used? When you do decide to implement them, how do you determine the fundamental 'building block' (i.e., the least divisible geologic object) of your region or route system? What are the ramifications of exporting data with region or route system topology to other GIS software? These questions need to be addressed in order to thoroughly exploit the utility of these powerful tools.

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Production of USGS Map I-2669 — A Folio of Maps and 3-D Images

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In the map area in east-central Illinois, extensive sands and gravels are buried within a thick sequence of glacial deposits. These sands and gravels constitute a highly productive regional aquifer, supplying water to numerous cities and communities. Through a collaborative effort between the Illinois State Geological Survey (ISGS) and the U.S. Geological Survey (USGS), the surficial, glacial deposits have been mapped using newly-developed 3-D mapping methods. The project's goals were to: 1) create a database of key stratigraphic information; 2) develop new methods for computer-aided mapping and presentation of data; 3) produce an integrated set of geologic maps and 3-D views for each glacial unit; and 4) use the geologic maps to help build a regional groundwater management tool.

The new mapping methods were described at the Digital Mapping Techniques workshop in 1998 (Soller, 1998, and <http://pubs.usgs.gov/openfile/of98-487/soller4.html>). These methods produced, in raster format, a set of maps of the complex subsurface geology that is internally consistent and that can form the geologic framework for a regional groundwater flow model. Three-dimensional views of each map were developed, to aid visualization. [Text, selected maps, and animated views of the images are available at <http://ncgmp.usgs.gov/ecill/>.] The maps and images were assembled into a formal USGS map product according to the following procedure.

In the study area, eight stratigraphic layers were mapped. For each layer, maps of unit elevation and unit thickness were created in Arc/Info Grid. Elevation data were imported into EarthVision, to create the 3-D images. The maps and screensaves of the images were converted to Postscript format. These files along with the photographs and text were imported into Adobe Illustrator where the composition of the formal USGS map product was completed. Plots generated on a HP3000 inkjet plotter at a resolution of 600 dpi served as proofs during the editing process, and as interim products. The high resolution of these interim plots made them highly effective tools for rapidly communicating the project's results to scientific audiences and to potential public- and private-sector cooperators in future projects.

Production of USGS Map I-1970 — A Regional Map Showing Thickness and Character of Quaternary Sediments

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In the 1980's, the geology shown on USGS Map I-1970-A, -B, -C, and -D was compiled according to traditional methods, using ink on mylar. The draft map showed the thickness and character of Quaternary sediments in the United States east of the Rocky Mountains, at a scale of 1:1,000,000. The map area at this scale is more than 30 square feet. The geologic information was contained on four separate mylar overlays. The map contained a highly complex portrayal of the geology, and it was determined that conventional methods of map production would yield a substandard product because of difficulties in registering color separations with peelcoats. In 1987, after discussion between author and cartographer, it was decided that the emerging technology of computer-based mapping might offer the precision needed to produce high-quality printing negatives. Also, in discussions with potential users of the map information, it became clear that if the map were in GIS format, its utility would be significantly enhanced.

Methods for producing this type of map did not, however, exist in 1987. Therefore, we sought and obtained funding through the USGS Director's "sweepstakes", which awarded "seed money" to selected projects that proposed to develop innovative methods in GIS and digital cartography. In 1988-89, we developed a method for scanning the manuscript maps, manipulating the digital map data, and outputting the data as color separates for map printing. This method required a Tektronix 4991 autovectorizing scanner, Arc/Info, and a Scitex Response-80 editing workstation and film writer. Details of the method were published as a user's manual (Soller and others, 1990). Although the hardware specifications described in the publication are no longer useful because of technological advances, the general approach and processing steps (e.g., methods for map registration) still are applicable.

In the early 1990s, the manuscript maps were scanned and edited in Arc/Info by the authors and by others. Data files then were submitted to the National Mapping Division for processing on the Scitex and for the generation of negatives to make proofs. These negatives were registered to negatives of the conventional greenline base map. Text and figures were produced as graphic files and placed manually; when assembled, the package was submitted for printing. The first of these maps, I-1970-A, was published in 1993 (Soller, 1993). The last map, I-1970-B, was published in 1998. The edited digital data also were used to build a geographic information system (GIS) database for analysis. The digital data were published as USGS DDS-38 (Soller and Packard, 1998), which is online at <http://pubs.usgs.gov/dds/dds38>.

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Offset Printing of Raster Image Files

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The Virginia Division of Mineral Resources has an ongoing commitment to vectorizing both new and previously published geologic maps in Virginia. Our goal is to provide not only paper maps but also GIS layers. We have digitized over half of our published maps and several previously unpublished maps. In getting to this point, we have had to deal with many issues. This paper will discuss one of these issues, specifically the use of offset printing to produce the required initial quantity of a map.

OVERVIEW OF HISTORY AND METHODOLOGY

The Virginia Division of Mineral Resources (VDMR) became interested several years ago in creating digital geologic GIS layers and in reducing publication costs by using digital production methods. It was important to avoid redundancy of effort by digitizing a map only once while meeting both goals. When none of the existing software met our needs, the Virginia Division of Mineral Resources helped to develop customized software.

The software is MS-DOS-based and runs on MS Windows systems. Data entry involves "heads-up" tracing of lines, creation of polygons, attribution of lines and areas, and entry of point data (strike and dip, well locations, etc.) over scanned images. Undergraduate geology majors have done the bulk of this work. DMR staff does the subsequent editing. All digital maps undergo the same detailed scrutiny as used in final editing of any traditionally produced map. The time required to digitize existing geologic maps varies with complexity and scale of the original map ranging from 15 days for a 1:24,000 quadrangle to 60 days for a complete 1:100,000 map.

We create a raster image of the geologic map from vector files that replicate the original published (paper) map in all respects. Geology, in color, appears over a subdued topographic/culture base. The raster image can be distributed on a CD-ROM, via the internet, or plotted on our HP Design Jet 2500 CP. Publishing a geologic map image on a Web page or CD-ROM has the advantages of quick distribution and low storage costs. However, many clients still want a paper copy and either do not have the ability to print in color or want the entire map printed. Plotters allow printing of high-resolution large paper maps and allow an agency to avoid storage costs for low demand maps.

OFFSET PRINTING TO MEET INITIAL QUANTITY REQUIREMENTS

In Virginia, the Division of Mineral Resources is required to supply 45 copies of a newly published map to various library collections. After the initial sales of another 40 to 50 copies, the demand then drops to one copy per month or less. We have found it to be impractical to print the initial 80 to 100 copies using an inkjet printer. Our alternative is to establish conventional offset printing as a means of meeting the initial demand, since it is still the most economic way to produce larger quantities of a map.

In a cooperative venture with the USGS, a standard output raster image of a geologic map was sent to the USGS printing shop. Adobe PhotoShop was used to convert the raster file of the finished map from RGB (red, green, and blue) to CMYK (cyan, magenta, yellow, and black), for ink trapping enhancements and color separation. The CMYK plate-making negatives were written on a large-format film writer. Traditional four color printing methods were then used. Experience shows that the process from color separation through printing requires fewer than eight man-hours, including time on the press, and that the quality of the resultant print is as good as that produced by traditional manual cartographic methods.

Costs

In the past, we paid $6,000 - $25,000 for 700 copies of a 1:24,000 quadrangle map depending on the map complexity and paper. We printed 700 copies partly because we divided the production cost by the number of copies produced in order to derive a selling price. Printing a larger number did not increase the printing costs as much as it decreased the final selling price for the map.

However, eighty percent of the production cost of printing a color geologic map was the cost of scribing and making peel coats. By using a raster image, we only have to pay the actual cost of printing. Therefore, the number of copies needed to have a reasonable per copy selling price is lower. The minimum number of copies printed depends on the type of printing press, the cost of setting up a print run and the type of paper.

In addition to lower production costs, we save time because we do not have to make line weight and color guides, nor create mylars for structure and formation symbols. Another advantage is that we can proof the map prior to sending it to the press because we are able to see how the text, symbols, line weights, and patterns will look on the printed map.

Problems Creating a Raster Image for Offset Printing

PPI

Some issues associated with offset printing need to be addressed. Two of the most notable are resolution of the digital image (pixels per inch or PPI) and color shifts. When determining PPI for a raster image, the question usually comes down to resolution versus file size. The higher the resolution, the more clear and the less blocky the detail. If the image is to be published digitally or even printed on an inkjet plotter, the only limitation is the size of the image file, which can rapidly become unmanageable as the PPI increases. However, for an image going to an offset printing press, there is another consideration. At higher PPI's too much ink is put on the paper causing the map to be dark. The general rule of printing is the PPI should be two times the lines per inch (LPI). LPI changes depending on the paper and the press. LPI generally ranges between 72 and 150. We have gotten good results with image resolutions of 250 and 300 PPI. We want to create only one final image file for each map that can be published digitally or printed on inkjets or run through an offset printing press. For this reason, we settled on an image resolution of 300 PPI, which preserves sufficient detail, produces a file of manageable size and produces a good-quality print (though a little dark).

Color Shifts

We are in the process of resolving the issue of color shifts. The problem is that computer monitors create images by using red, green and blue (RGB) light. Inkjet plotters/presses generally use cyan, magenta, yellow and black (CMYK) ink. Some colors that can be created using RGB cannot be duplicated using CMYK. These colors are said to be "out-of-gamut." Out-of-gamut colors look muddy when printed because the position in color space has been shifted slightly to bring it within the CMYK gamut or range of colors. It is difficult to predict the appearance of a printed map that was created in RGB.

One solution is to use "Spot" colors in the printing process. Spot colors are specific inks created to produce a specific color not in the CMYK gamut. Since the color produced is not the result of a combination of four colors but rather one ink with a defined composition, the color is always the same. The classic use of spot colors is in the reproduction of logo colors like "3M blue" where it is important to the company that the color is the same every time it is used. On geologic maps, red is perhaps one of the more important colors that is difficult to reproduce in CMYK. Red spot ink is used sometimes as a fifth color in CMYK printing to obtain a true red. Using spot colors can be very expensive since an individual mask plate is necessary for every color.

Another solution is to only use colors that are in the "common gamut". The common gamut is that range of colors common to both RGB and CMYK; therefore, no shift is necessary. Some programs display a gamut warning and offer substitutes. It can be time consuming to go through every "out-of-gamut" color on a map and find a substitute particularly if the image does not use a color palette. Furthermore, RIPing programs that translate an image into plotter language can cause color shifts. This is most noticeable in the yellow, which frequently develops greenish tones. It necessary to adjust the program's gamma curve. Not all programs allow the user to do this.

The issue of color shifts is further complicated by the unreliability of using an inkjet plotter to proof colors for offset printing. Most inkjets use dye inks while offset printing presses use pigmented inks. Dye inks are water-soluble with the color in solution tinting the water. The ink is somewhat translucent and is susceptible to fading upon exposure to UV light. Pigmented inks, on the other hand, are oil-based and the color is produced by tiny particles of pigment suspended in the ink. Pigmented inks are more resistant to fading and are more opaque than dye inks. Pigmented ink is available for the HP DesignJet 2000 series printers. We have noticed that blues in particular are different when printed in dye ink and pigmented ink.

While it is possible to buy pigmented ink for inkjet printers and calibrate a monitor and a RIPing program to approximate the CMYK press colors, it is still only an approximation which must be constantly maintained because ambient light, warmth of the cathode tubes and a myriad of other things affect our perception of color. Because of the difficulty of proofing offset printing colors ahead of time, many people who are only interested in the printed result use one of several specific color systems, for example TruMatch® and Pantone®. Each of these systems has a swatch book printed on an offset printing press under specific conditions. These swatch books allow you to see how a color will look when printed. Once you select a color from the swatch book, you either enter the code for the color or the CYMK values for the color. The major image processing programs like Adobe Photoshop, CorelDraw, and Canvas support these two systems.

The Division of Mineral Resources has not reached a definitive solution to the color problem. We will probably use a combination of the solutions mentioned above to develop a chart of defined colors to be combined with patterns for various formations in Virginia. Our goal is to produce one final raster image for each map where the image will look the same regardless of how it is displayed or printed. In order to discern different formations within the same age, colors need to maintain their distinctiveness when they are printed. We are working with the USGS printing office on this problem. Together, we have created two TIF files: a RGB color chart and a CMYK color chart. The USGS is planning to print the CMYK color chart on their offset printing press. It is possible to send the color chart TIF files through various combinations of RIPing programs to various printers. Using these charts and perhaps the TruMatch swatch book and color system, we will create a standard set of colors for each unit following the international stratigraphic color scheme.

CONCLUSION

The Virginia Division of Mineral Resources has successfully created an acceptable offset-printed map from a 300 PPI raster image file. Sending digital image files to an offset printing press enables us to economically print the initial number of copies required to release a newly published map with significant savings in both time and money. We are planning to use this procedure for offset printing of digital files to publish all new maps.

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Quaternary Landforms in Wisconsin — How Hillshading Can Be Used To Accentuate Topographic Features

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The topography of the land surface is a direct result of the type of geologic materials that underlie the surface and the geologic events and processes that acted on them. Therefore, the shape of the land surface can provide important clues to many aspects of the Earth's history.

In contrast to the dominant landforms in the mountainous regions of North America, where topographic relief can exceed 5,000 ft over relatively short distances, the central lowlands of the United States are characterized by relatively low relief topography. Elevations in Wisconsin vary by only 1,500 ft across the entire state, and so Wisconsin landforms tend to be smaller in scale and more difficult to view from a regional or statewide perspective. Glaciated and unglaciated regions dominate Wisconsin's topography, and there are topographic features that are unique to each region.

Throughout the past two million years, continental glaciers repeatedly flowed across much of what is now the northern United States. All but the southwestern quarter of Wisconsin has been covered by ice at different times; most of the glaciated part of the state was glaciated during the Wisconsin Glaciation (Clayton and others, 1991). As the ice sheets advanced and receded, features such as drumlins, eskers, and moraines were formed. Glacial activity was recent enough in many parts of the state to be the dominant influence on the modern landscape.

The effects of stream incision dominate the topography of southwestern Wisconsin, which was never glaciated. Years of drainage have worn down the surface into a highly dendritic network of water channels (Clayton and Attig, 1997).

When evaluating geologic history, a map that effectively displays the way in which topography differs from area to area is usually essential. Topography can be portrayed a number of ways: contour lines, oblique or stereo aerial photography, and shaded relief. Shaded relief maps provide a means of viewing topography that requires little or no interpretation. As an analytical tool, these maps can provide the geologist with a unique regional perspective of topography. The ease with which a shaded relief map can be interpreted also makes it an effective teaching tool. The advent of digital geographic information systems, along with readily available digital elevation data, has made the creation of shaded relief maps fairly straightforward, not the highly interpretive and onerous task it once was. The subtle nature of Wisconsin's topographic variations, especially in the glaciated regions, necessitates the use of a highly detailed elevation model to derive an effective shaded relief map.

Until recently, statewide digital elevation data were available only in 500-meter and 75-meter raster format; these data were too coarse to show the fine topographic detail that dominates the landscape in the glaciated parts of the state. Complete 30-meter USGS DEM coverage of the state recently became available. The Wisconsin Department of Natural Resources (DNR) compiled the approximately 1,200 30-meter DEMs that make up the state into a seamless grid in Arc/Info.

To derive the hillshading on this map, I used the techniques described by Haugerud and Greenberg (1998). Their methods involve the use of the GRIDCOMPOSITE command with the HSV option in ARCPLOT. This command makes use of the HSV color model, where hue ranges from 0 to 360, saturation from 0 to 100, and value from 0 to 100, as shown in Figure 1. Essentially, GRIDCOMPOSITE combines three grids representing HUE, SATURATION, and VALUE into a composite image. The combination of the analytical power of GRID with the multi-band imaging flexibility of the HSV model results in an effective visual technique.

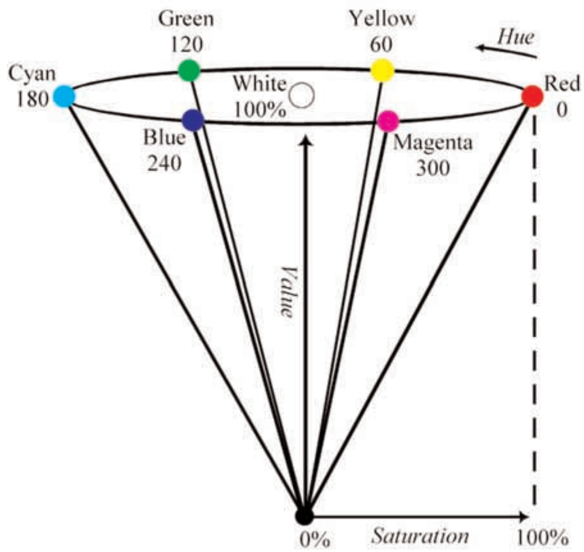


Figure 1. HSV color model (reprinted with permission from “Specifying Color,” ESRI ArcDoc 7.2.1).

For this map I wanted the color to be dependent upon elevation. I decided to use a range from green at the lowest elevations to orange at the highest elevations.

I created a HUE grid where the HUE values stretched linearly from green at the lowest elevations to orange at the highest elevation. I had to do the same with the SATURATION grid, only using the SATURATION values that represented my colors. I used the following formulas in GRID:

<HUE_GRID> = [H_{LOW}] - [H_{LOW} - H_{HIGH}] * ((<DEM> - DEM_{MIN}) / (DEM_{MAX} - DE_{MIN}))

and

<SATURATION_GRID> = [S_{LOW}] - [S_{LOW} - S_{HIGH}] * ((<DEM> - DEM_{MIN}) / (DEM_{MAX} - DEM_{MIN}))

where: [H_{LOW}] is the Hue component of the HSV color representing the lowest elevations;
[H_{HIGH}] is the Hue component of the HSV color representing the highest elevations;
[S_{LOW}] is the Saturation component of the HSV color representing the lowest elevations;
[S_{HIGH}] is the Saturation component of the HSV color representing the highest elevations;
DEM_{MIN} is the minimum elevation; and

DEM_{MAX} is the maximum elevation.

In the HSV color model, color is mainly dependent upon the H and the S values (just as in CMYK, color is mainly a function of C, M, and Y). In this technique, the VALUE grid controls the hillshade effect. Consider that for any pixel of color specified by HUE and SATURATION, the VALUE component sets the amount of black. For instance, a HUE of 120 and a SATURATION of 50 will specify a medium light green. If the VALUE is 0, the resultant HSV color will be black. Similarly, if the VALUE is 100, the resultant color will be the medium light green with no black as a part of the color. This is the effect of shading – shaded areas are blacker than illuminated areas.

Haugerud and Greenberg (1998) note that the contrast of most images produced by the HILLSHADE command in Arc/Info is not suitable for use in this process. They suggest modifying the standard hillshade via the following technique:

&describe <hill_shade_grid>
xxg1 = (<hill_shade_grid> - [Value GRD$MEAN]) * 15 / [value GRD$STDV] + 95)

Because GRIDS in Arc/Info are always rectangular, I had to manipulate the NODATA cells so that they would not print black. I found that the easiest way to do this was to convert the NODATA areas of the HUE, SATURATION, and VALUE grids into a white color. In HSV, white is any H value, S = 0, and V = 100. Using conditional statements in GRID, I converted the values of the HUE, SATURATION, and VALUE grids to their white equivalent wherever the original DEM was NODATA.

The final step in this process was to convert the three grids into a geo-referenced TIF image. The geo-referenced TIF draws faster than the three grid composite and can be displayed in ArcView. To create the image from my HUE, SATURATION, and VALUE grids, I first created RED, BLUE, and GREEN grids using the HSV2RED, HSV2BLUE, and HSV2GREEN commands. I then combined the three grids into a stack using the MAKESTACK command using the LIST option. Finally, I used the GRIDIMAGE command to convert the STACK into a TIF image.

I have attached the AML I used for this process in the appendix.

REFERENCES

Arc/Info 7.2.1- ARCDOC, 1997 [Computer Program], available from: Environmental Systems Research Institute, Redlands, CA.

Clayton, Lee, and Attig, J.W., 1997, Pleistocene Geology of Dane County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 95, 64 p.

Clayton, Lee, Attig J.W., Mickelson, D.M., and Johnson, M.D., 1991, Glaciation of Wisconsin: Wisconsin Geological and Natural History Survey Educational Series 36, (revised 1992), 4 p.

Haugerud, Ralph, and Greenberg, H.M., 1998, Recipes for Digital Cartography: Cooking with DEMs, in Soller, D.R., ed., Digital Mapping Techniques ’98—Workshop Proceedings: U.S. Geological Survey Open File Report 98-487, p. 119-126, <http://pubs.usgs.gov/openfile/of98-487/haug2.html>.

APPENDIX

```
/********************************
/* HSV.AML
/********************************
/*
/* COLORED HILLSHADE PROGRAM
/*
/* Use this program to generate a colored shaded relief
/* image.  Color will be a function of elevation.
/* The user is required to supply the HSV color equivalents
/* of a LOW elevation color and a HIGH elevation color
/*
/********************************
/*
/* Primary Developers:     Chip Hankley - GIS Specialist
/*                         Wisconsin Geological and
/*                         Natural History Survey
/*
/* Derived from work by Ralph A. Haugerud(1) and
/* Harvey Greenberg(2)
/*
/*  (1)  U.S. Geological Survey at University of Washington, Box
/*    351310, Seattle, WA 98195, rhaugerud@usgs.gov
/*  (2) Dept. of Geological Sciences, University of Washington,
/*    Box 351310, Seattle, WA 98195, hgreen@u.washington.edu
/*
/********************************
/*
/* Date of Initial Coding:  8/17/98
/* Date of Last Edit:       3/25/99
/*     Combined several different AMLs into one coherent module
/*    using routines.  This should run on all platforms.
/*
/*
/********************************
/*
/* Available from:          ARC
/* Arguments:               ZGrid, Hue_l, Sat_l, Hue_h, Sat_h
/*
/*     ZGrid: the DEM !!!NOTE!!! The DEM must be FLOATING POINT
/*     Hue_l: Hue of the LOW elevation color
/*     Sat_l: Saturation of the LOW elevation color
/*     Hue_h: Hue of the HIGH elevation color
/*     Sat_h: Saturation of the HIGH elevation color
/********************************
/*  BEGIN THE PROGRAM
/********************************
```

```
/* Program Setup
&args ZGrid Hue_l Sat_l Hue_h Sat_h
&severity &error &routine bailout
&term 9999
display 9999
/********************************
GRID     /* start GRID
&describe %ZGrid%
&sv cell = %grd$dx%
/********************************
&call v
&call h
&call s
&call draw
&call image
&call exit
&return
/********************************
/* ROUTINES
/********************************
&routine v
&sv azim = 315
&sv inclin = 45
initial = hillshade(%ZGrid%,%azim%, %inclin%, shade)
&describe initial
xxg1 = (initial - [Value GRD$MEAN]) * 15 / [value GRD$STDV] + 95
v = con(xxg1 <= 70, 70, xxg1 <= 99, int(xxg1), isnull(xxg1), 99, 99)
kill (!xxg1 initial!) all
v1 = con(isnull(v), 100, v)
kill v all
rename v1 v
setwindow v
&return
/********************************
&routine h
&describe %ZGrid%
h =  %hue_l% - (%hue_l% - %hue_h%) * ((%ZGrid% - %grd$zmin%)/(%grd$zmax% - %grd$zmin%))
h1 = con(isnull(h), 0, h)
kill h
rename h1 h
&return
/********************************
&routine s
&describe %ZGrid%
s = %sat_l% - (%sat_l% - %sat_h%) * ((%ZGrid% - %grd$zmin%)/(%grd$zmax% - %grd$zmin%))
s1 = con(isnull(s), 0, s)
kill s
rename s1 s
&return
/********************************
&routine draw
mape v
gridcomposite hsv h s v
&return
/********************************
&routine image
```

```
  &sv nm = dem_hill
  r = hsv2red(h, s, v)
  g = hsv2green(h, s, v)
  b = hsv2blue(h, s, v)
  makestack stack1 list r g b
  arc gridimage stack1 # %nm% tiff
  kill stack1 all
&return
/********************************
&routine exit
&if [show program] ne ARC &then q
&if [EXISTS h -GRID] &then
  kill h all
&if [EXISTS s -GRID] &then
  kill s all
&if [EXISTS v -GRID] &then
  kill v all
&return
/********************************
/* Perform Cleanup actions if Program Fails
&routine bailout
&severity &error &fail
&call exit
&return &error Bailing out of HSV.aml
```

APPENDIX A

List of Attendees at the Digital Mapping Techniques '99 Workshop

[Grouped by affiliation]

Alaska Division of Geological and Geophysical Surveys
Frank Ganley

Arizona Geological Survey
Steve Richard

Arkansas Geological Commission
Steven Hill
Jennifer Perkins

Avenza Software Inc.
Susan Muleme

California Division of Mines and Geology
Dave Wagner

College of William and Mary
Karen Berquist

Delaware Geological Survey
Lillian Wang

Dynamic Graphics, Inc.
Skip Pack

Environmental Systems Research Institute, Inc.
Mike Price

Florida Geological Survey
Jon Arthur
Amy M. Graves

Geological Survey of Alabama
Nick Tew

Geological Survey of Canada
Eric Boisvert
Boyan Brodaric
Vic Dohar
Dave Everett

Hewlett-Packard Company
Al Berry

Idaho Geological Survey
Tim Funderburg
Loudon Stanford

Illinois State Geological Survey
Curt Abert
Sheena Beaverson
Rob Krumm
Barb Stiff

Intergraph Corporation
Jeff Hyatt

Iowa Geological Survey
Mike Bounk

Kansas Geological Survey
David Collins
Elizabeth Crouse
Gina Ross
John Siceloff

Kentucky Geological Survey
Warren H. Anderson
Jason A. Patton
Rick Sergeant
Tom N. Sparks
Xin-Yue Yang

Louisiana Geological Survey
Robert Paulsell
R. Hampton Peele

Maryland Geological Survey
Lamere Hennessee

Minnesota Geological Survey
Tim Wahl

Missouri Division of Geology and Land Survey
Hal Baker
Chris Vierrether

Montana Bureau of Mines and Geology
Debbie Smith
Larry Smith
Susan Smith

National Park Service
Steve Fryer

Nevada Bureau of Mines and Geology
Gary Johnson

New Jersey Geological Survey
Zehdreh Allen-Lafayette

New Mexico Bureau of Mines and Mineral Resources
Mark Mansell
Dave McCraw
Becky Titus

North Dakota Geological Survey
Ann Fritz
Karen Mitchell
Ryan Waldkirch

Ohio Geological Survey
Tom Berg
Jim McDonald

Oklahoma Geological Survey
Wayne Furr

Ontario Geological Survey
Brian Berdusco

Oregon Department of Geology and Mineral Industries
Mark Neuhaus

Pennsylvania Geological Survey
Bill Kochanov
Tom Whitfield

Tennessee Division of Geology
Elaine Foust

U.S. Air Force
Alyssa Perroy

U.S. Geological Survey
Greg Allord
Dave Bedford
Todd Fitzgibbon
Bruce Johnson
Diane Lane
Gary Latzke
Bob Lemen
Jonathan C. Matti
Missy Packard
John S. Pallister
Peter Schweitzer
Dave Soller
Nancy Stamm
Will Stettner
Ron Wahl
Gregory Walsh
John Watermolen

University of California, Santa Barbara
Jordan Hastings

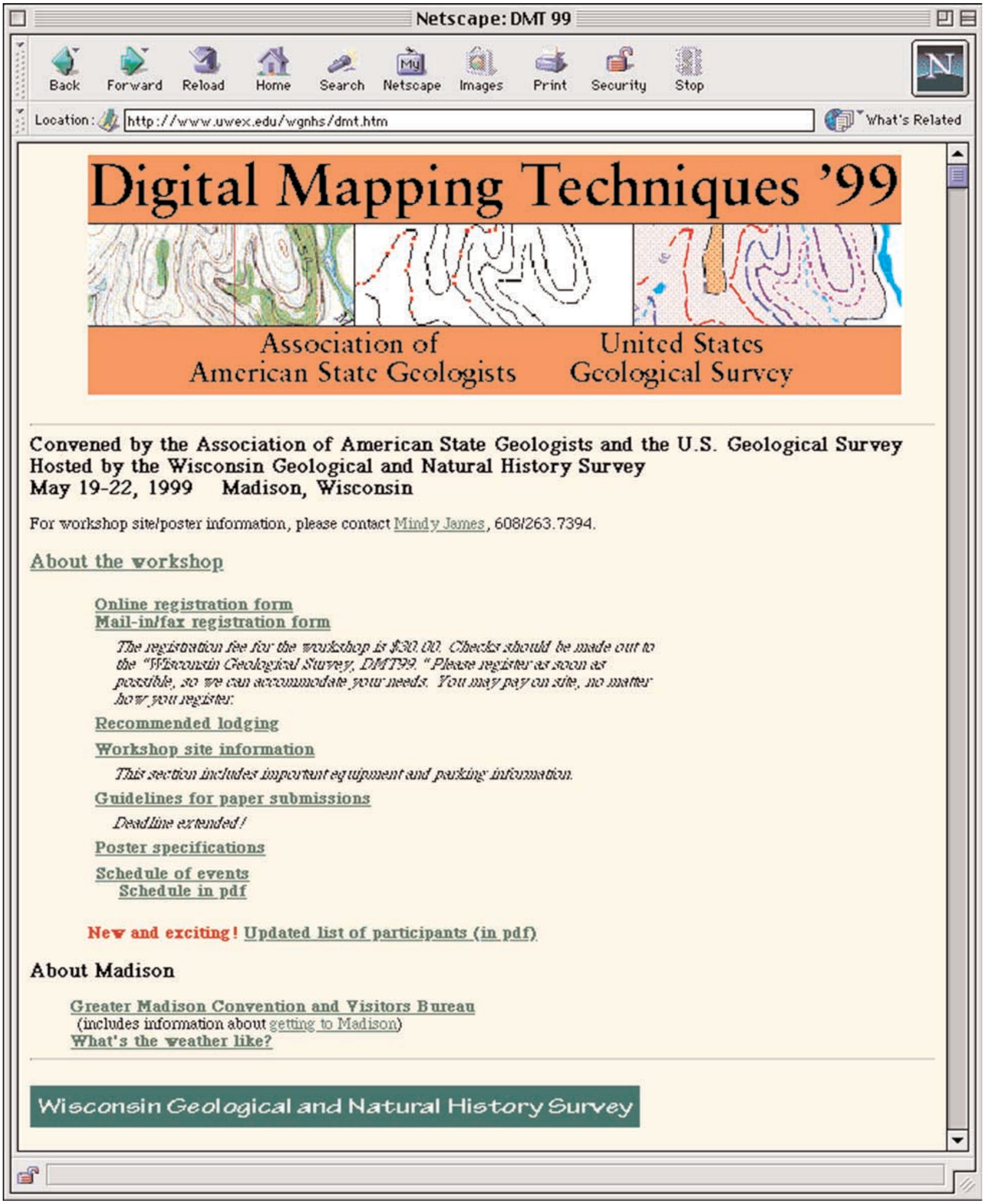
Utah Geological Survey
Kent D. Brown

Virginia Division of Mineral Resources
Rick Berquist
Elizabeth Campbell
Ryan Perroy

West Virginia Geological and Economic Survey
Scott McColloch

Wisconsin Geological and Natural History Survey
Bill Bristol
Mike Czechanski
Chip Hankley
Mindy James
Deborah Patterson
Kathy Roushar

APPENDIX B
Workshop Web Site



APPENDIX C

List of Addresses, Telephone Numbers, and URLs for Software and Hardware Suppliers

[Information contained herein was provided mostly by the authors of the various articles and has not been checked by the editor for accuracy]

Adobe Illustrator, Photoshop, Acrobat, and PageMaker - Adobe Systems Inc., 345 Park Ave., San Jose, CA 95110-2704, (408) 536-6000, <http://www.adobe.com>.

ALACARTE – U. S. Geological Survey, <http://wrgis.wr.usgs.gov/docs/software/software.html>.

Anatech Scanner - Intergraph Corp. Corporate Headquarters, Huntsville, Al 35894-0001, (256) 730-2000, <http://www.intergraph.com>.

Apple Newton hand-held Personal Digital Assistant and Macintosh - Apple Computer Inc., 1 Infinite Loop, Cupertino, CA 95014, (408) 996-1010, <http://www.apple.com>.

Arc/Info, ArcView, ArcScan, ArcPress, ArcExplorer and ArcCad - Environmental Systems Research Institute (ESRI) Inc., 380 New York St., Redlands, CA 92373, (714) 793 2853, <http://www.esri.com>.

AutoCAD, AutoCAD Map 3.0, and MapGuide - Autodesk Inc., 20400 Stevens Creek Blvd., Cupertino, CA 95014-2217, (408) 517 1700, <http://www.autodesk.com>.

Canvas - Deneba Software, 7400 S.W. 87th Avenue, Miami, FL 33173, (305) 596-5644, <http://www.deneba.com>.

CorelDraw - Corel Corp., 567 East Timpanogos Parkway, Orem, UT 84097-6209, (801) 765 4010, <http://www.corel.com>.

Data General – Data General Corporation, 3400 Computer Drive, Westboro, MA 01580, (508) 898-5000, <http://www.dg.com/>.

DBASE database software - dBASE, Inc., 2548 Vestal Parkway E, Vestal, NY 13860, (888) dBA-SE32, <http://www.dbase2000.com/>.

Delphi - Inprise Corporation, 100 Enterprise Way, Scotts Valley, CA 95066, (831) 431-1000, <http://www.borland.com/>.

EarthVision - Dynamic Graphics Inc., 1015 Atlantic Avenue, Alameda, CA., 94501-1154, (510) 522-0700, <http://www.dgi.com>.

Genasys Products - Genasys Systems Pty Ltd, Level 13, 33 Berry Street, North Sydney, NSW 2060, Australia, telephone 61-2-9926-2800, <www.genasys.com>.

GSMAP and GSMCAD - U.S. Geological Survey, <http://ncgmp.cr.usgs.gov/ncgmp/gsmcad/GSMCW5.HTM>.

GSView and Ghostscript - Aladdin Enterprises, 203 Santa Margarita Ave., Menlo Park, CA 94025, (650) 322-0103, email: ghost@aladdin.com, <http://www.cs.wisc.edu/~ghost/index.html>.

GTX-OSR vectorizing software - GTX Corporation, 2390 East Camelback Road, Ste. 410, Phoenix, AZ 85016, (800) 879-8284, email: info@gtx.com, <http://www.gtx.com/>.

Hewlett Packard DesignJet Series Plotters (various) - Hewlett-Packard Co 8000 Foothills Rd., Roseville, CA 95747, 1-800-PACKARD, <http://www.hp.com>.

IDRISI - Clark University, 950 Main Street, Worcester, MA, (508) 793-7526, <http://www.clarklabs.org>.

LtPlus raster-to-vector conversion software – <http://ftp.digital.com.au/pub/grass421>.

LT4X - AverStar, Inc., 4099 SE International Way, Portland, OR 97222, (503) 794-1344, <http://www.averstar.com/gis/software_products.html>.

Macromedia Freehand - Macromedia Inc., 600 Townsend St., San Francisco, CA 94103, (415) 252-2000.

MapInfo - MapInfo Corporate Headquarters, One Global View, Troy, NY 12180, (800) 327-8627, <http://www.mapinfo.com>.

MapPublisher - Avenza Software Inc., 3385 Harvester Rd. Suite 205, Burlington, Ontario, Canada L7N 3N2, <http://www.avenza.com>.

Micrografx Designer - Micrografx, Inc., Richardson, Texas, (972) 994-6525, e-mail: pr@micrografx.com, <http://www.micrografx.com>

Microstation Products - Bentley Systems, Incorporated, 685 Stockton Drive , Exton, PA 19341-0678, (800) 236-8539.

Onyx Postershop - Onyx Graphics Corporation, Salt Lake City, UT, <http://www.onyxgfx.com>

ORACLE - Oracle, Inc., 500 Oracle Parkway, Redwood Shores, CA 94065, (800) ORACLE1, <http://www.oracle.com/corporate/sales_offices>.

Palm handheld organizers - Palm Computing, Inc., a 3Com Company, 5400 Bayfront Plaza, Mail Stop #10112, PO Box 58007, Santa Clara, CA 95052-8007, (408) 326-5000, <http://www.palm.com>.

Pendragon Forms – Pendragon Software Corporation, P.O. Box 7350, Buffalo Grove, IL 60089, <http://www.pendragon-software.com>.

Petra software - geoPLUS Corporation, 8801 South Yale, Suite 380, Tulsa, OK 74137, (888) PETRA-65, <http:.//www.geoplus.com/html/petra.shtml>.

PLGR - Rockwell Collins Headquarters, 400 Collins Road NE, Cedar Rapids, IA 52498, (319) 295-5100, <http://www.collins.rockwell.com/government-systems/products/gpssmdex.shtml>.

Scitex - Scitex America Corp., 8 Oak Park Drive, Bedford, MA 01730, Fax: (781) 276-5709, <http://www.scitex.com>.

Smallworld database software - Smallworld Systems Inc., 5600 Greenwood Plaza Blvd., Englewood, CO 80111, (303)779-6980, <http://www.smallworld.co.uk/services/worldwide_contacts.asp>.

Sun, SUNOS and SOLARIS 2.5.1 - Sun Microsystems Inc., 901 San Antonio Rd., Palo Alto, CA 94303, (650) 960-1300, <http://access1.sun.com>.

Tektronix - Tektronix, Inc., 26600 SW Parkway, Wilsonville, OR 97070, (800)TEK-WIDE, <http://www.tek.com/>.

Trumatch - 50 East 72nd Street, Suite 15B, New York, NY 10021-4242, (800) 898-9100, <http://www.trumatch.com>.

Versatec plotters - Xerox Engineering Systems - Versatec Products, 5853 Ruserrari Avenue, San Jose, CA 95138 USA, (408) 229-3071,<http://www.engineeringsystems.com/index.htm>

Windows95 and WindowsNT - Microsoft Corp., One Microsoft Way, Redmond, WA 98052-6399, (425) 882-8080, <http://www.microsoft.com>.