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Digital Mapping Techniques '00—Workshop Proceedings

Edited by David R. Soller

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Lexington, Kentucky

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Association of American State Geologists
and the
United States Geological Survey

Hosted by the
Kentucky Geological Survey

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By David R. Soller

U.S. Geological Survey
908 National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6937
e-mail: drsoller@usgs.gov

The Digital Mapping Techniques '00 (DMT'00) workshop was attended by 99 technical experts from 42 agencies, universities, and private companies, including representatives from 28 state geological surveys (see Appendix A). This workshop was similar in nature to the first three meetings, held in June, 1997, in Lawrence, Kansas (Soller, 1997), in May, 1998, in Champaign, Illinois (Soller, 1998a), and in May, 1999, in Madison, Wisconsin (Soller, 1999). This year's meeting was hosted by the Kentucky Geological Survey, from May 17 to 20, 2000, on the University of Kentucky campus in Lexington. 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; 3) progress toward building a standard geologic map data model; 4) field data-collection systems; and 5) map citation and authorship guidelines. Four representatives of the GIS hardware and software vendor community were invited to participate.

The four 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/>). 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 Kentucky Geological Survey (KGS), and their Chief and State Geologist, James Cobb, for hosting this very productive and enjoyable meeting. I especially thank Warren Anderson (KGS), who coordinated the meeting, provided excellent support for the attendees, and managed the maintenance of the meeting's web site (see Appendix B). Thanks also to Jason Patton, Doug Curl, Steve Martin, Julie Back, Lynda Mutasek, Tom Sparks, Mike Murphy, Mike Solis, Mark Thompson, Xin Yue Yang, Geaunita Caylor, Barry Bowman, Shawn Duncan, Mark Tyra, Sarah Hawkins, and Kim Toth (KGS and the University of Kentucky) for helping with the meeting logistics. 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; Adam Davis (USGS) for help with the Appendices; and

Nancy Polend for typesetting these and the previous two Proceedings. 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."

The papers are generally organized by topic, from field data systems through database design, standards, and data models, to creation, management, and delivery of map publications and data. Information about the software and hardware referred to in these Proceedings is provided in Appendix C.

POSTERS

More than 25 posters were exhibited throughout the workshop. These posters provided an excellent focus for technical discussions and support for oral presentations. Many are documented with a paper in these Proceedings, following the oral presentations; the other posters generally provided material in support of oral presentations, and so are not documented herein.

DISCUSSION SESSIONS

To provide the opportunity to consider a topic in some detail, special discussion sessions are held at the DMT workshops. This year there were two: 1) geologic map authorship and citation guidelines, and 2) a general discussion of ideas presented during the meeting. Discussion session #1 began by revisiting the presentation of ideas and suggestions proposed at DMT'99 by Rick Berquist (Virginia Division of Mineral Resources, <http://pubs.usgs.gov/openfile/of99-386/berquist.html>). Steve Richard's presentation (Arizona Geological Survey, this volume) then offered additional and new thoughts on the subject. The ensuing discussion led to development of a strategy — during the coming months, workshop attendees will discuss in their agency the policies or informal guidelines for map authorship and citation; these ideas will be submitted to the Data Capture Working Group in preparation for a more focused discussion at the next Digital Mapping Techniques workshop, hopefully leading to development of guidelines or examples that may be considered by each agency. Session #2 provided recommendations for new features to add to future DMT meetings.

THE NEXT DMT WORKSHOP

At discussion session #2, it was decided that a fifth annual DMT meeting would be held next year, hosted by the Geological Survey of Alabama. While planning for that event, the Data Capture Working Group will carefully consider the recommendations offered by DMT'00 attendees.

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Digital Geological Knowledge: From the Field to the Map to the Internet

By Boyan Brodaric

Geological Survey of Canada
234B-615 Booth St.,
Ottawa, Canada
K1A 0E9
Telephone: (613) 992-3562
Fax: (613) 995-9273
e-mail: Brodaric@gsc.nrcan.gc.ca
and
The Pennsylvania State University
GeoVISTA Center,
Department of Geography,
333 Walker Bldg.
University Park, PA 16802-5011
Telephone: (814) 237-3916
Fax: (814) 863-7943
e-mail: bmb184@psu.edu

INTRODUCTION

Field data represents a core geological information base. It is essential to geological map creation and is the ultimate reference when compiling regional maps from detailed field generated source maps. As such, the manner in which field information is structured and manipulated has long-reaching effects on geological data management, and on the effective organization and dissemination of geological knowledge. New technologies in field data capture, storage, manipulation, map database management, as well new Internet possibilities, require an information strategy that can be applied to field and map information in Internet environments. Moreover, such a strategy must accommodate the transformation of geological information to non-geological domains, in support of societal concerns such as sustainability, biodiversity, climate change, etc., all of which stand to benefit from the input of geological information. This paper will review some information strategies presently used for the management of field data and map information, and discuss potential strategies for their migration to Internet environments. Improved geological knowledge will result from the development and implementation of a common geoscience data model, one that will facilitate the export of geological knowledge to other knowledge domains. Examples illustrating these points will be drawn primarily from ongoing efforts at the Geological Survey of Canada (GSC) and U.S. Geological Survey (USGS).

KNOWLEDGE MANAGEMENT: MAP INFORMATION COLLECTION

Geologic knowledge is comprised of our cumulative understanding of the Earth's materials and processes. This knowledge is derived from sampling geologic conditions and subsequently developing four-dimensional spatio-temporal models of the Earth's system. Sampling is performed via human observation, typically field-based, or via instrumentation which may be either field-based or remotely located. Because this empirical information forms a critical knowledge base and constitutes the ultimate reference for any subsequent model development, it must be thoroughly captured. Capturing information via instrumentation without human intervention is relatively straightforward, but digitally recording the complex knowledge schemes used by humans when considering geologic situations is more daunting. New technologies are providing opportunities for enhanced knowledge capture, but they also introduce many complexities during implementation, as their orientations are frequently not geological. Integrating human requirements and practices with emerging field-based technologies poses new challenges that must be overcome in order for digital geologic field data to be an effective recourse for geologic decision-making.

Since the 1980's, the Geological Survey of Canada has been deploying various technologies to augment field-based geologic surveying and to develop a digital base of geologic field information. These efforts have been largely successful in migrating manual field data management techniques to digital methods, but they have been arguably less successful in stimulating new scientific practices and insights. Mylar and ink have been admirably replaced with computer screen and keyboard, resulting in effective and efficient map production and database construction, but scientific progress resulting from these advances has not kept pace. What are the barriers to such progress? The following sections explore this question by summarizing past and present GSC efforts, and by identifying problem areas and potential solutions.

Deployment and Results

Since its initial development at the Ontario Geological Survey (Brodaric and Fyon, 1989; 1990), and later continued development at the GSC (Brodaric, 1997), the Field*Log* geologic field mapping system has attained wide and varied usage (e.g., see Figure 1).

The successful deployment of this system has benefitted both corporate entities and individual scientists, mainly by improving the efficiency of transforming data from a single data store to other formats, and from one media to another; e.g., from notebook to map. For individuals this has meant an overall reduction in the manual labor associated with various cartographic, data management and analysis tasks, both in the field and in the office. For the agency, more efficient on-site field data management has enabled more data, and more data types, to be assimilated in the field, permitting the launching of more complex mapping programs involving multi-disciplinary teams (Broome et. al., 1993). It has also led to timely and cost-effective information distribution, as data is digitally managed from its inception to its release, from the field through to publication (Figure 2). Products are now released in some or all of the following formats: on traditional paper, on CD-ROMs, and also via the Internet.

These successes may be largely attributed to (1) a flexible system design that could be tailored to a broad spectrum of geological and administrative conditions and goals, and (2) readily available and knowledgeable technical support. It is the former factor, that of system design, that is of specific interest here.

Methods

A system that accommodates the wide variety of geologic conditions and project objectives must necessarily be flexible. It must provide diverse options for determining geographic position, for structuring and recording geologic observations on-site (at the outcrop), and for manipulating the observed information so as to facilitate geologic interpretation. For example, the Field*Log* system provides options in all three categories (Figure 3). Geologists may digitize estimated site locations or geologic features from topographic maps and air photographs, or they may obtain geographic locations and feature extents via satellite positioning systems. Various hand-held computer types are used to record data on the outcrop, though traditional field notebooks may also be used for on-site note-taking followed by the manual entry of data into the digital database at the field camp. Lastly, a host of cartographic and analytic tools is provided to visualize data and thus aid geologic interpretation and map construction (for more details see Brodaric, 1997).

Apart from flexibility, field systems should also be easy to use. Ease of use and flexibility, however, tend to be inversely proportional; indeed, as the FieldLog system has expanded it has become more complex. How to retain flexibility without sacrificing usability? The challenges to be overcome may be categorized as being either technologic or geologic.

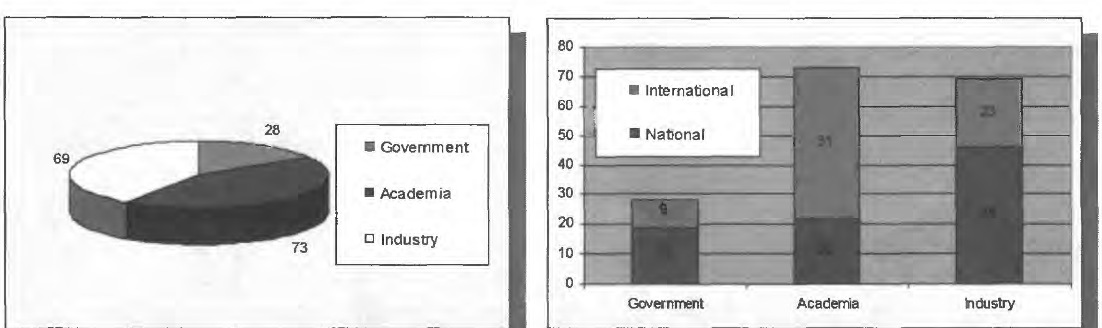

Figure 1. The scope of FieldLog usage measured by number of individuals downloading the software from the web site during 1998-1999.

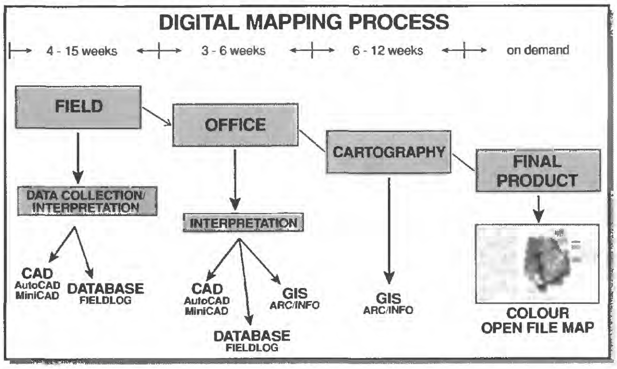

Figure 2. The stages and approximate duration of the digital map production process at the GSC (this figure from K. Baker, GSC, per. comm.).

Challenges: Technologic

Mobile computing, geographic positioning, and geologic information management provide a technologic basis for field computing. Each of these categories is characterized by increasing technological change and hence tremendous diversity. For example, mobile computing devices range in size and functionality and include palmtops, handhelds and laptops. Positioning technology is also changing with more accurate readings made available over a variety of media such as satellites, radio and telephone, and new devices such as laser range finders are emerging. Field information systems are also proliferating to serve various purposes (e.g., Briner et. al., 1999).

This admixture may be portrayed as a *technologic* space consisting of four axes: (1) mobile hardware, (2) information, (3) positioning and (4) telecommunication (Figure 4, left). The challenge with this mix of technologies is to select the appropriate combination for the project at hand, which amounts to selecting the optimal point in this technologic space. Yet, how is one to stay abreast of rapid technologic change, and how can geologic field systems unify these diverging elements into convergent solutions such that technology will be developed to serve geological needs a *priori*, rather than awkwardly adapted afterwards? It is clear that to generate convergence in this space the geologic community must take control of whatever factors it can. This amounts to seizing control of its information requirements and thereby reversing the expansion of the information axis, effectively shrinking the technologic space and eventually coercing developments in the other axes towards geologic information requirements (Figure 4). In short, enhancements in geologic information modeling and management may provide a nucleus upon which developers of technology can create geologic solutions. This is quite opposite to the current trend in field systems, where systems are composed of a loose cobbling of diverse technologies, each demanding a unique and complex expertise.

Challenges: Field Geologic

Many physical and human factors beyond the technologic also affect the ability of individuals and agencies to develop field-computing solutions. The geographic and geologic environment, the scale of endeavor, the stated purpose of the fieldwork as well as expertise of the personnel, all influence and may dictate the configuration of the optimal field system. For example, mountainous terrain has varied field-computing requirements: areas of high relief require portable hardware, pose challenges to satellite access, and require 3D positioning and information management. Some vegetated areas, on the other hand, are dominated by ground cover rather than topography, and are thus more attuned to remote sensing techniques that classify or penetrate ground cover. Apart from physical and geologic conditions, geographic scale also affects field-computing solutions. Regional surveying efforts demand portable hardware, moderate positional accuracy, and focus on information synthesis, whereas detailed initiatives exhibit the converse traits of low hardware portability, high positional accuracy, and information analysis. Lastly, human factors such as costs, technologic literacy, scientific expertise and experience, as well as corporate and political agendas, also significantly motivate field programs and hence the configuration of field systems.

Figure 3. Examples of the three main technologic factors influencing field system design: geographic positioning (left), on site data recording (middle), and information management and manipulation for geologic interpretation (right). Photos courtesy of various geologists from the Geological Survey of Canada.

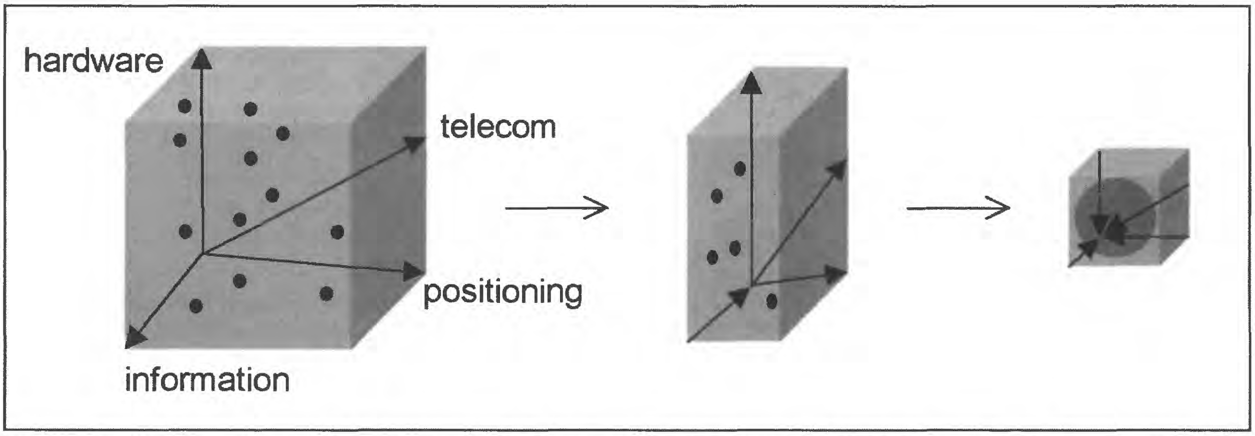

Figure 4. Reducing the number of potential field system solutions involves diminishment of the growing technology space (on the left) via information modeling and management; this should in turn attract geologic-technologic developments to further reduce the space, effectively concentrating the range of technologic solutions.

Like their technologic counterparts, these non-technologic variables (i.e., physical geography, geologic conditions, scale and human factors) may also be portrayed as the base axes of a space—a *field geology* space (Figure 5, right). However, unlike the *technologic* space such a *field geology* space is relatively static, as technology changes much more rapidly than, say, physical geography or geologic theory. Controlling certain human factors such as technical literacy may aid in managing this space, however, the degree to which political and economic variables can be directed is arguable, as is the degree to which their often drastic effects can be mitigated by improved technical know-how. Consequently, the predominant challenge in configuring field system solutions involves matching field geologic situations within a relatively static geologic space to an expanding space of technologic solutions. This can be visualized as matching a point in field geologic space to one in technologic space (Figure 5). Success in this is predicated on the presence of individuals possessing expertise in both spaces, implying a prerequisite shift in geoscientific personnel profiles and education practices. Appropriating the technologic space by modeling and managing information, as suggested above, should allay the severity of this knowledge shift and should provide a framework for geo-technologic dialog and education. But, how to do this?

Solutions: Information Modeling and Management

The complexity of geologic situations, the expanding nature of technologic solutions, as well as the uncertainty of appropriately matching situations to solutions, suggests there is at present no field system panacea. As for the future, only the information axis would seem capable of being leveraged so as to reduce the overall size of the *technologic* space and thereby simplify the matching problem (Figure 6). We see this trend prevalent in related disciplines, most notably in the geospatial (OpenGIS Consortium, 1999) and petroleum (POSC, 1999; PPDM, 2000) industries, where information standards and operational guidelines are concentrating technologic develop-

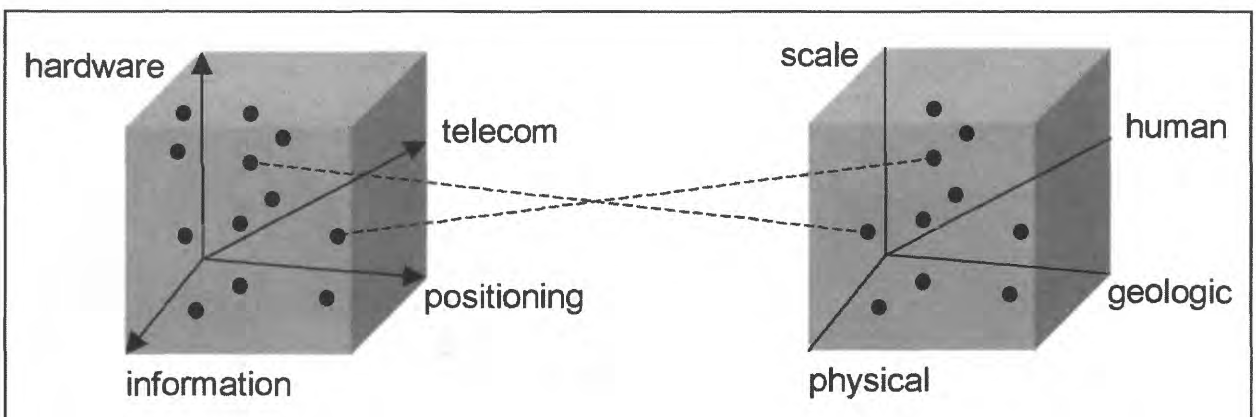

Figure 5. Field system configuration involves appropriately matching a geologic situation in the field geologic space (on the right) to a technologic solution in the technologic space (on the left).

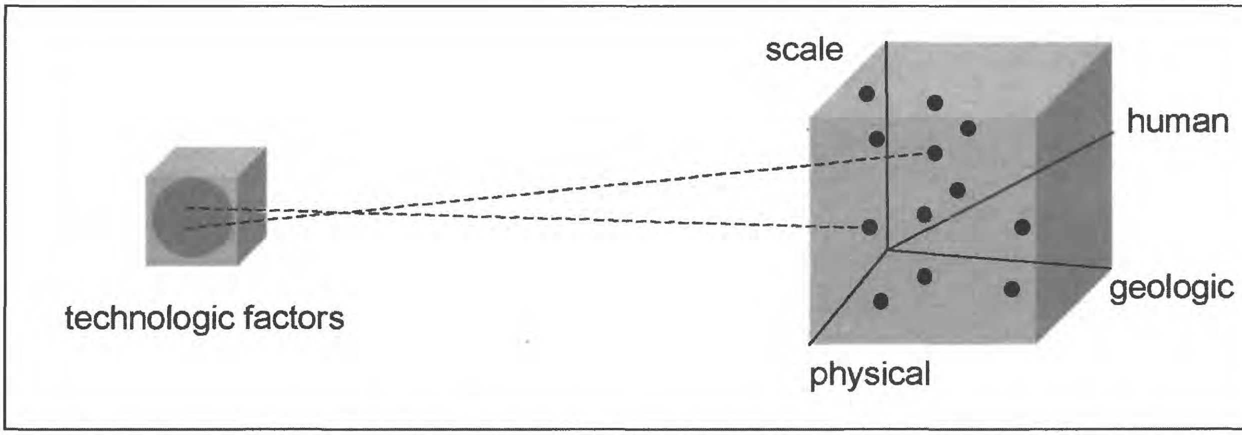

Figure 6. Improved matching of geologic situation (right) with technologic solution (left) by reducing the number of field system solutions. Enhanced information modeling and management should result in more concentrated technologic development along all technologic axes: i.e., defining information guidelines and operational requirements should attract and focus the development of technologies, shrinking the technologic space (left), and consequently improving the integration of diverse technologies for geologic field computing purposes. This should in turn reduce duplicate development, technologic dispersion, education requirements, and lead to quicker revision cycles for technology.

ment, to the avowed overall benefit of both data producers and users. Leveraging the geologic information axis involves enhancing our mechanisms for managing (1) information content, and (2) information structure.

Information content issues are related to the access, delivery, and utility of the information: they are concerned with how geologic information is reached and used. The explosion in the use of the Internet, and the subsequent chaotic availability of large amounts of heterogeneous data, have caused both government (Broome, 2000) and academia (AGU, 2000) to call for the management of these resources in some coordinated and pooled fashion. Growing awareness of the need to demonstrate relevance to society indicates these systems must also provide a bridge between geology and other knowledge domains (e.g., climate change, environment, etc.), possibly through software transformations (Journeay, et. al., 2000). This involves capturing information and reasoning techniques traditionally held in the minds of the geologist, implying that improved geologic information utility is related to developing enhanced structures that draw upon the way humans represent and reason with geologic information. The concern with such structures here does not imply that the various other technical and political hurdles to be overcome are insignificant, as they are not, yet if inadequate structuring of information renders it mostly unusable, then all else is for naught.

Information structure issues are concerned with optimizing how geologic interpretation is represented, and how it is constructed via reasoning. Some geologic problems are reasonably well constrained and the interpretative element diminished, permitting geologic features to be directly modeled in our digital data representations (as per most geologic data models: e.g., Bain and Giles, 1997; PPDM, 2000; Richard, 1999). Other problems such as the construction of geologic histories from field data are less constrained (Burns and Remfry, 1976), requiring that the nature of the interpretation leading to the geologic feature be emphasized in the data modeling (Brodaric and Gahegan, 2000). As the source of much geologic interpretation (and thus geologic knowledge) is derived from field data, the digital structuring of field data may not only play a key role in the design of a geologic information system, but the issues encountered in structuring field data may also underlie many issues encountered in structuring geologic interpretation. Indeed, it may prove to be the case that representing undisputed geologic features may be a subset of the problem of representing the geologic interpretations that define a feature. How then do we represent a geologic interpretation?

Field observation, as a scientific form of human interpretation, may be described as the interplay of developing *scientific* and *mental* models (Brodaric, et. al., 2000; Loudon, 2000). The scientific model consists of how existing scientific theory is applied, while the mental model consists of how personal knowledge and experience is brought to bear (e.g., possibly tacit—Loudon 2000). Both may possess interpretative elements. For example, data may be limited due to the open nature of the Earth's systems and this may imprecisely constrain the geologic history (i.e., the *scientific* model), resulting in multiple valid hypotheses from which the best must be selected (Martin, 1998; Schumm, 1991). On the other hand, various human factors such as personal experience and training (i.e., *mental* models) may also bias observation and subsequent interpretation. The degree to which adjacent map boundaries may differ when mapped by various individuals (e.g., Figure 8, later) attests to the prevalence of one or other interpretative aspect (or both) in the knowledge construction process. The information structuring issues in this devolve to (1) reasoning with insufficient information that leads to multiple valid *scientific* models, and consequently (2) representing geologic features with various interpretations.

Reasoning from information with gaps is a human strength and a computer weakness. It is reasonable to question the degree to which such human reasoning can be emulated computationally. Nevertheless, pursing the development of human-like inference mechanisms to augment various data processing tasks would seem not only to be fruitful but also necessary for the effective usage of geologic data, and thus for the transcription of human knowledge into digital form. Some efforts to develop such reasoning mechanisms for geology include: (e.g., Flewelling, et. al., 1992; Harrap and Helmstaed, 1998; Simmons, 1983; 1988; Sakamoto, 1994).

The second issue, concerned with representing various interpretations, is a very prominent problem in GIS interoperability (Bishr, 1998) but is one that has received scant attention geoscientifically. Some interrelated key issues include: (1) the nature of geologic feature identity; (2) the depiction of meanings; (3) the depiction of scientific models; and (4) the depiction of three-dimensional geometry and topology, particularly to aid geologic reasoning.

Features are typically portrayed as being *simple* and having constant and unique identity (e.g. Open GIS Consortium 1999; ISO TC211, 1999; and less so in POSC, 1999). However, the spatial, temporal and descriptive aspects of a geologic feature are often variable, due to scientific disagreement or changes over time and scale; or they are uncertain, due to classification ambiguity (Haugerud, 1998; Figure 7). Geologic information structures must therefore accommodate features that are complex and possess variable and uncertain identity. Moreover, the concepts used to describe established features may themselves conflict and require conceptual clarification or semantic disambiguation; e.g., this situation is often encountered in stratigraphic lexicons where multiple terms may be synonymous, where terms may have multiple meanings or multiple names, or be otherwise related. Enhancing identity and semantics would signify an improvement in geological representation. However, identifying features and explicating their meanings does not constitute a geologic interpretation, for this merely describes what features are and not how they fit together in space and time. Additionally required is a notion of a scientific model as an intentional and particular collection of features, their meanings and geometries, held in concordance with scientific theory—the geologic map shorthand for this is a legend (and is exploited as such by the North American Geologic Map Data Model (NADM): Raines, et. al., 1997; Johnson, et. al., 1999). In summary, this implies that features, models, theories all need to be digitally represented and their particular spatial, temporal and categorical relations depicted.

If these representational issues related to identity, semantics, and models are indeed fundamental, then their impact should extend beyond field information and encompass other forms of geologic interpretation such as regional map synthesis. This is briefly explored next.

KNOWLEDGE MANAGEMENT: GEOLOGIC INFORMATION SYNTHESIS

The construction of regional geologic synthesis is an important duty performed by many geologic agencies. The prevalence of digital geologic information provides opportunity to enhance traditional methods with digital aids, and indeed, also offers the potential for new information products that are more dynamic. For example, it is conceivable to expedite the generation of regional syntheses by leveraging a digital database of sources via a human-aided expert system (e.g., Colman-Sadd, et. al., 1996), followed by Internet distribution. The implications for geological data providers are far-reaching, as regional syntheses could be maintained real-time, and the lengthy cycles between revisions dramatically reduced.

Representing and reasoning with geologic information is clearly central to the synthesis task. Yet, how pervasive are the representational issues of identity, semantics, and models, particularly when synthesizing geologic information in order to develop regional geologic interpretations? In the development of regional syntheses multiple sources are integrated into an aggregate entity that is scientifically cohesive. However, spatial scale, spatial resolution, available theory, and data all may contribute to a situation in which the sources may possess varying scientific features, meanings or models (e.g., Figure 8). Correlating and integrating these elements is essential to developing syntheses, and this requires representational and reasoning devices to reconcile between diverse element occurrences (i.e., features, meanings, models) in various source data. Reconciling between diverse scientific models is related to the evaluation of multiple valid models in field interpretation, indicating that the issues found in field information representation and reasoning broadly pervade the synthesis task. This implies that identifying some general and common structuring core for geologic field and synthetic information may be feasible and should be sought.

A final concern is the impact of the Internet on geologic information utility, including synthesis. The immediate and obvious conclusion is that the Internet is primarily a communications medium that has minimal intrinsic bearing on the structuring of geologic information. The Internet's hypertext links do permit the construction of a network of documents, but without additional structure this does little to resolve the representation issues related to

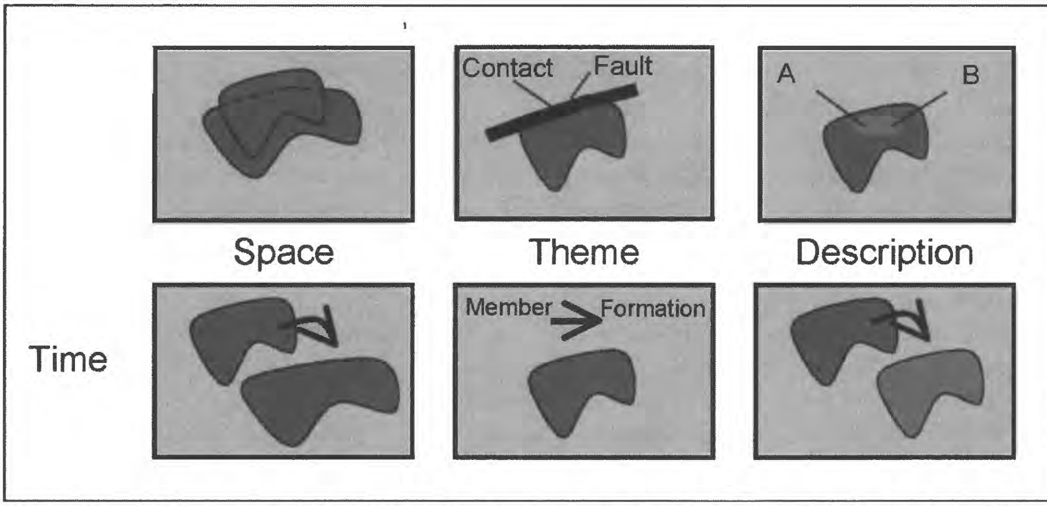

Figure 7. Ambiguous geologic feature identity in space, theme and description; due to variable categorization at one time (upper row) and to changes in time (lower row). In the upper row, a geologic feature may be variously interpreted at the same point in time due to diverse opinions regarding the feature's spatial extents, categorization and description, or due to scale constraints. In the bottom row, a geologic feature's spatial extents, categorization, or description may change in time due to increased understanding of the feature, or due to physical changes in time arising from geologic processes acting on the feature.

geologic feature identity, semantics, and models, and, moreover, the Internet provides little inherent reasoning capacity. What the Internet does provide is a substructure onto which such elements could be grafted, and furthermore, due its broad usage, it also provides tremendous incentive and opportunity to do so.

One ramification of increased Internet usage is heightened awareness of information incompatibility, and collaterally, awareness of the need to facilitate the sharing of seemingly incompatible information sources. Apart from the many policy and technical issues attached to data ownership (now being addressed by the e-commerce community—e.g., <http://www.rosettanet.org/>), the main obstacle to such information sharing is representational in nature: the ability to represent and interoperate with diverse geospatial concepts is less advanced than our to ability to share diverse spatial database formats or distribute data via the Internet (Bishr, 1998). It is this situation in particular that hinders the on-line synthesis of model-based geologic information (e.g. geologic map information). Though it is reasonable to question the degree to which automated on-line synthesis is possible, it is also reasonable to assume that enhanced structuring of geologic interpretation (including models, features, semantics, and multi-model reasoning) could only aid both automated or expert-driven synthesis, and in this prove altogether beneficial. For example, providing an infrastructure to aid human directed on-line synthesis should facilitate the development of new scientific interpretations (possibly expressed as maps) and thereby contribute to the advancement of some geoscientific knowledge. Moreover, it could also aid in the transformation and transfer of geoscientific information to other knowledge domains, and thus not only meet a prevailing societal imperative but also contribute to the notion of the overall value and utility of geoscientific knowledge.

In essence, the Internet provides ample incentive, opportunity, and a new medium, for geologic information synthesis, but it does not resolve the underlying information structuring issues that pervade synthesis. Indeed, the rapid introduction of various, often competing, Internet developments may act to complicate these issues, as evolving geologic information solutions must cope with relative-

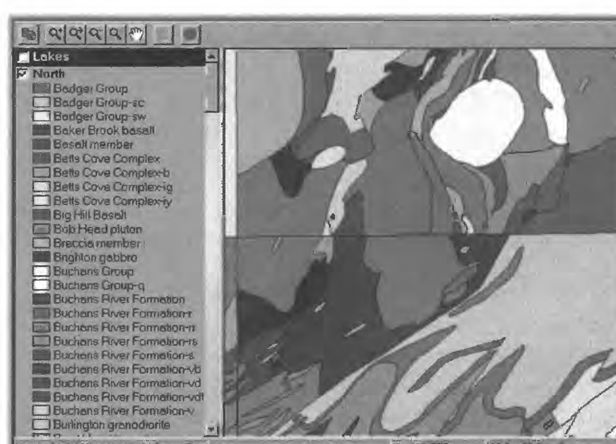

Figure 8. Variable geologic interpretations of the same geographic area, drawn from a digital geologic map database prior to synthesis (from Davenport, et. al., 1999).

ly fledgling Internet advancements. For example, recent technical developments in the areas of information exchange such as XML (Extensible Markup Language: <http://www.w3.org/TR/>) and RDF (Resource Description Framework: <http://www.w3.org/TR/>) provide a means of adding context to documents, thus boosting the information structuring capacity of the Internet, yet two outstanding questions remain in this. Firstly, XML and RDF are not domain specific and require the pre-existence of an appropriate geologic data model; secondly, their suitability in representing such a data model, one that encompasses geologic interpretation, is unknown. Exploration of XML and RDF by the geologic community (e.g., XMML: <http://www.ned.dem.csiro.au/XMML/>) will contribute to the clarification of these unknowns, particularly when incorporating geologic data models that are map-based and/or inclined to modeling geologic interpretation (e.g., NADM: <http://geology.usgs.gov.dm/>). This necessary emphasis on information modeling, and its critical position vis a vis technologic development, reinforces the previous suggestion that information modeling not only provides a means of evaluating technology but also possesses the capacity to influence its progress, whether the focus is on field systems or the Internet.

In summary, progress in various Internet areas is quickly providing a foundation for information synthesis by facilitating the rapid assembly of diversely located and formatted information in conjunction with an evolving sensitivity to issues of diverse data ownership, proprietary revenue policy, and other information-related practices. What is missing is the know-how and infrastructure to integrate this information geologically, across different themes and geographic areas. This signals an opportunity not only to develop Internet-based geoscientific networks in which data content may be accessed and manipulated, and where proprietary rights are observed, but it also identifies geologic information structuring as a critical task. The scientific and societal benefits of developing such networks for the geosciences could be substantial, and must be exploited by the geoscience community to ensure its viability as both a knowledge generator and a knowledge provider in this 'age of information'.

CONCLUSIONS

The development of enhanced geologic information structuring techniques, as well as the tools to exploit them, is essential to harnessing the full potential of our geologic knowledge in the field, in the office, and on the Internet. The benefits derived from enhanced reasoning and representation techniques should extend beyond the sphere of data managers, and should impact geological practice and thus geological insight. Better information structure should lead to better tools and enhanced interpretation aids, and moreover, a *common* structure, one that is widely acknowledged, should attract vendors and focus tool development. Moreover, this should leverage the various multitudinous efforts that have until now been quite divergent.

For these benefits to be realized it is incumbent on the geoscience community to partake in the various ongoing information structuring efforts. But, herein lies the crux of the matter, for traditional geoscience has often neglected the *form* of its information in favor of its *content*. The so-called 'information age' can no longer support such neglect, and the various efforts to remedy this by geoscience information providers attests to their acknowledgment of this fact (e.g., CGKN—Broome, 2000; GEIXS: <http://www.eurogeosurveys.org/>; NGMDB—Soller and Berg, 1999). When these efforts evolve from sharing catalogs (i.e., metadata) to sharing and using actual information content—as required by information synthesis—then several deep representational and reasoning problems related to geologic feature identity, semantics, geologic models, and reasoning with knowledge gaps will need to be resolved. Their eventual resolution represents a goal and a challenge that must be met for the successful participation of the geosciences in the 'information age'.

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Digital Mapping Systems for Field Data Collection

By John H. Kramer, Ph.D.

Condor Earth Technologies, Inc.
21663 Brian Lane
Sonora, CA 95251-3905
Telephone: (209) 532-0361
Fax: (209) 532-0773
e-mail: jkramer@condorearth.com

INTRODUCTION

Modern mapping technologies enable geologists to create and visualize maps in a digital format while on the outcrop. Such "born digital" maps (Fitzgibbon, 1997) provide new opportunities and pose new challenges to state geological surveys and the USGS. A new generation of geologists trained in digital technologies is emerging from University programs, notably the Earth Resources Center Digital Mapping Lab at UC Berkeley. These digitally literate field geologists can create field products that port directly into publishable format, or to the Internet for wide distribution.

Digital mapping technologies are changing the way geologists create maps in the field. Field computers now link field geologists to digital versions of pre-existing maps and ortho-photographs, while providing full edit, line-creation and area-fill capabilities. Laser range-finding devices and Global Position System (GPS) receivers provide field geologists with accurate tools for locating geologic features in the field. Mobile analytical instruments, such as soil gas analyzers, magnetometers and IR spectrometers expand the scope of field mapping tasks and provide field mappers immediate feedback to refine sample locations and prospect for meaningful data points. Geologists with digital cameras can attach photo files to symbols on digital maps while in the field.

In this paper, I summarize the technologies currently being deployed for creating and editing geologic maps in the field. Modern hardware and software are described along with the apparent trends in their development. Some examples of their application to geologic mapping are given. Also described is a field-to-Internet link in which camera locations and resulting digital photo panoramas are displayed on a web site where they are used to calibrate and validate computer-renderings of potential future landscapes. This process provides direct field feedback to an open-access technology for disseminating information to the public, which is consistent with the mission of government information agencies such as the state geological surveys and USGS.

TOOLS

Hardware

Hardware for digitally based geologic mapping generally includes a computer and compatible input devices. Computers that operate in a Microsoft Windows environment include ubiquitous laptop computers, pint-sized variants like the Panasonic CF-M33, a number of tablet pen-computers (dominated right now by Fujitsu), and lesser-known but highly field-portable wearable computers (e.g. Via). A step down in capability and cost, but of lighter weight and smaller size for field applications are the palm-sized computers. These operate either in Windows CE (and its next-generation Pocket PC operating system), or the less battery-dependent Personal Data Assistants (PDA) operating in Palm OS. The hand held computer market is rapidly developing, with new models appearing about every 90 days.

Accessory hardware includes an array of laser range-finding devices and survey instruments, digital cameras, many GPS input systems (several manufacturers provide autonomous and differentially corrected systems), and direct-sensor input from analytical equipment. In addition to survey total stations, more ruggedized equipment is available, such as the laser binoculars shown in figure 1. These are equipped with an internal digital compass, inclinometer, and reflectorless laser range finder. Data is accurate to within 1 degree and 1 m (up to 4 km) and exports data via RS232 serial interface to field computers. Laser

Figure 1. Laser binoculars with compass, inclinometer, and data output cable

Figure 2. Sunlight-readable color displays became available for the first time in 1999.

recycle rate is about a point every five seconds, which allows for rapid mapping of distant points or moving targets, for example, a migrating oil slick.

The latest and greatest advancement in field hardware is the sunlight-readable color displays that hit the market in 1999. For the first time geologists can see displayed field maps in the sunlight without shading the screen and squinting. These displays are built into pen computers, palm-sized computers, or are tethered to belt-worn or backpacked laptops as shown on figure 2. Until these screens were available, geologists could only work in sunlight using gray scales on transflexive monochrome displays. The mapper shown in figure 2 also has a backpack containing a differentially corrected GPS receiver that provides precision at the sub-centimeter level.

Hardware is constantly improving, but only in the past two years have the computers, screen technology, battery life, GPS and other peripheral devices become enabling tools for geologists to efficiently create digital maps in the field.

Software

Numerous software solutions for digital field data collection have been developed for different operating systems and hardware platforms. In this section several will be described, from the simplest to the most complex. The major GPS manufacturers: Leica, Garmen, Trimble, and Magellan to name four have produced various navigation aids and data loggers for their receivers. These software programs are generally written in proprietary operating systems for display of position and coordinates while in the field, and typically do not support direct input and output of maps. GPS-specific digital mapping aids are constantly being upgraded and both Leica (GS50) and Trimble (GeoExplorer3) have capability for GIS database update.

The USGS has used the note-recording software on hand held computers for collecting field notes in digital format (Williams, 1999; Walsh et al., 1999a; Walsh et al., 1999b). In these applications, field notes in electronic format were used to replace paper notebooks. These systems linked ASCII field data to position or time using GPS waypoints. Line data was digitized from a paper map and used in conjunction with GSMCAD (Williams et al., 1996), a Microsoft Windows program developed at the USGS for compilation of geologic maps, or with other map production software. Autodesk, the largest distributor of CAD software, has recently released OnSite, a mobile computing application on the Palm OS platform that supports positional data in a map format.

The Geological Survey of Canada developed the first well-implemented conversion from paper-based methods to digital field data collection using the Fieldlog software. Field data was collected in a digital notebook (Apple Newton) and linked to an AutoCAD/rdbms-based geologic GIS system as described elsewhere (Brodaric, 1997). The data-collecting software supports a relational geological database and ASCII files are transported into the more complex GIS mapping system at base camp. Another field-data entry software that interfaces very closely with the GSC system is Fieldworker. This commercially available product also developed for the Newton (now discontinued) has been converted to the Windows CE OS <www.fieldworker.com>. The system has been embellished to include an interface with GPS receivers and laser devices.

A competing CE-based mapping software developed for survey and mapping work that also interfaces directly with GPS receivers and laser devices is Solo CE by Tripod Data Systems. In addition, ESRI, developer of the popular ArcView GIS software, has launched a CE-based map/photo-reading, navigation and data collection product called ArcPad that uses the graphical user interface familiar to ArcView users. ArcPad employs the popular shapefile format and is compatible with the latest image-compression technology (Mr. Sid). It also comes with the backing of the largest GIS software supplier in the world.

All CE-based software will eventually have to convert to the Pocket PC operating system, Microsoft's next generation OS for palm devices. The reason for the name change has marketing pundits questioning the success of the CE-style OS for PDAs. Has Microsoft tried unsuccessfully to shoehorn too many PC capabilities into too small of a box, thus failing to compete with the scaled back PDA systems that very efficiently deal with limited, specific functions? Will Pocket PC be an upscale version of CE with a new name, or will it represent a retreat to the leaner type OS proven in the PDA market? From a geologic mapping standpoint the concept of a CE-style OS is superior because it supports faster processing, higher screen resolution with color display, larger input files and more complicated programming for map scroll and user interface. A disadvantage is shorter battery life than the streamlined Palm OS PDAs. Performance of CE-based software also limits functionality because screen redraws of complicated maps are very slow by desk-top PC standards. Field workers are not especially known for their patience, and CE-software cannot match the computing speed or power of a true Windows-based field mapping software.

The most complete, field tested, and proven Windows-based software for creating geologic maps in the field is the GeoMapper configuration of PenMap. Geomapper, owned by the University of California, was developed at The University of California Berkeley (UCB) as part of an undergraduate field geological mapping course (Brimhall, 1999), graduate digital mapping training and professional surface and underground mapping applications in mining and exploration geology. The strategy of the configuration is described by Brimhall et al. (1999) as follows:

> "The range of applications of GeoMapper/PenMap is broad and includes general geology, geomorphology, petrology, structural geology, mining geology, exploration, pedology, and environmental geology. In practical terms, GeoMapper is a computerized mapping legend which contains both the geological features needed to map the earth as well as a visual interface to use all the digital electronic equipment a user selects. The mapping tools include a pen stylus which serves the purpose of a full set of colored pencils. In combination with digital topographic maps or color ortho-photos on the screen of a portable computer for positioning, this is all that many users may require to undertake digital mapping. Additional digital tools include sub-meter accuracy GPS, laser range finders, digital cameras and visible/infrared (IR) spectrometers. Lithology symbols are included so that both black and white patterns can represent rocks and color can be used to show formations, structures (faults and veins), alteration and mineralization. GeoMapper is constructed from the standpoint of the end user who wishes to do geological mapping, sampling and surveying as soon as possible. It eliminates the complicated multiple steps of transferring paper maps to digital output by scanning and interpretation which can lose or corrupt information. Interpretation with GeoMapper is done in the field where models can be checked against nature. The organization of the visual interface is designed around the requirements of mapping practice and the structure of the files created is consistent with extraction of information to solve real problems."

Most useful for geologists are the automated buttons in Geomapper that set methods, layers, and line type for different customized geological mapping functions. To preserve screen space, additional buttons for lithology, formation, structure, mineralization and alteration cascade out of the legend if needed, as shown in figure 3. The 2000 Geological Society of America Annual meeting in Reno will include Topic Poster Session #70 on High Technology Tools for Geological Research and Practice, where Geomapper output will be on display. A complete presentation of the geological mapping system developed at UCB will occur at the Symposium on Geological Mapping at the Berkeley Earth Resources Center Digital Mapping Lab starting Friday November 17, 2000, immediately following the Reno GSA Annual Meeting. For details on the symposium, contact <brimhall@socrates.berkeley.edu>.

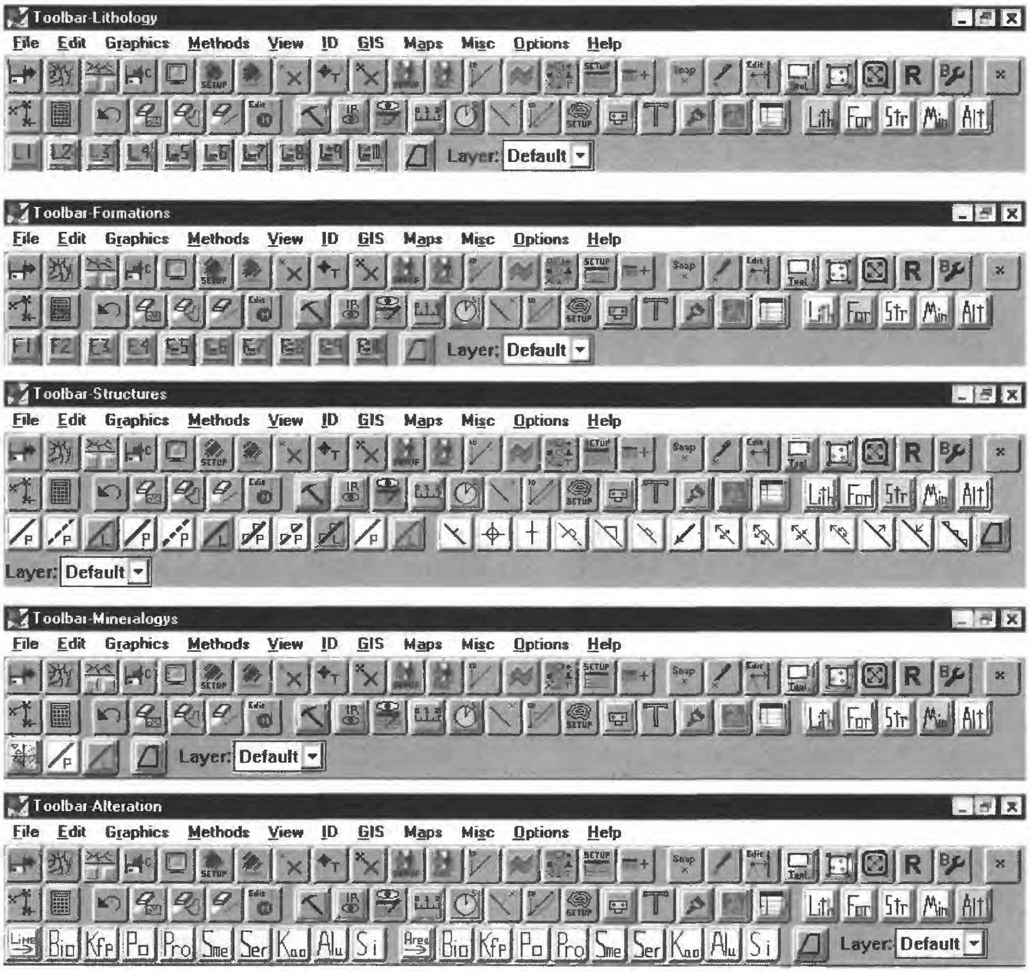

Figure 3. GeoMapper buttons for standard geological mapping functions and for different lithology, formation, structure, mineralization or alteration.

The underlying PenMap software is designed for data collection and interpretation of data in the field. The software retains metadata on the methods that were used to collect the 3-D position coordinates for all nodes used to create graphics, locate symbols, points, lines and polygons on the map. Useful features provided by the software include user-design of GIS databases, digital terrain modeling of up to five surfaces simultaneously (elevation and four GIS attributes), 16,000 drawing layers for GIS data control, CAD interface and convenient map display. PenMap imports and exports to a number of different file formats, including DXF and ArcView shape files. Many other features are described elsewhere (Kramer, 1997, 1998).

FIELD MAPPING SYSTEMS INTEGRATION

Field mapping systems integration is the process of defining the project needs and constraints, specifying the tools and training required for success, and monitoring progress. Systems integrators must select from a plethora of options along a continuum of complexity from the simple collection of numeric data, to the most advanced mobile computing options involving wireless communication and digital or video imaging. Add to this the hyper-evolution in the hardware market with frequent software rollovers, and one realizes that successful systems integration is like hitting a moving target.

In each instance, a unique set of criteria and requirements guides the choice of tools and the type of training needed for field mapping systems integration. Successful integrators must be visionaries who believe the efforts to implement a digital field mapping capability are outweighed by the potential efficiency gains. Successful systems integration specialists are those who require clear project definition, full commitment, thorough training, rapid deployment, and high utilization of equipment (before it becomes outdated). By achieving rapid results, the concept of digital mapping is proven. Then, upgrades become a desirable enhancement to a successful program.

System integration specialists assemble field systems of components from different manufacturers (computer, software, GPS, laser, bar code reader, etc). Examples of integrated high-end systems for PC-based mapping are Vectormap (laser capable) or the Digital Reconnaissance Set (laser and GPS capable), both of which cost approximately US$10,000 or more. Typically, because of limited volume, high end systems are customized individually for the intended application. Recently, as prices have come down, pre-assembled lower-end kits have become available. The Full Monty Package, consisting of a Compaq palm-sized computer running ArcPad linked to differential GPS (sub-meter accuracy), is selling for under US$3,000, which is less than the price of many differential GPS systems alone. Without the differential GPS, a user can begin digital field mapping on a CE platform for under $1,000 per unit.

DIGITAL FIELD MAPPING METHODS PROMOTE NEW USES FOR GEOLOGIC DATA AND MAPS

Brimhall (1998) noted the rising number of non-geology students who enroll in geologic field mapping courses in order to get training in field mapping techniques. These include biologists, engineers, environmental scientists, public policy majors and others who look to geologists for training. This diversity of interest in field data collection is also reflected in the history of commercial deployment of digital field mapping techniques. In addition to geologists, others who have employed digital mapping technology include pipeline constructors, archeologists, foresters, farmers, infrastructure inventory providers, surveyors, planners, police and the military.

The wide use of GIS for planning and infrastructure management creates the need and even the expectation for combining geologic data with other spatial information. As more and more digitally-literate field workers from all disciplines emerge from Colleges and Universities each year, we can expect to see the map-making capabilities of our state geological surveys and the USGS used by a wider spectrum of specialists, in new and unforeseen ways.

An example of one such unforeseen use is a project recently completed in which digital field mapping and photography supported computerized landscape renderings accessed via the Internet as described below. Using the World Construction set software, Condor created computer-generated landscapes from a digital elevation model (DEM). These were used to visualize modeled landscape changes associated with the build-out of a waste-rock dump at a mine. (We have also done renderings to visualize a future gravel quarry.) Such modeled visualizations can be more precise than artists' renderings and are useful for policy makers and the public unfamiliar with contour maps. Just as in other types of computer modeling, a calibration or validation process enhances confidence in the computer output.

For calibrating the rendering, a digital photograph mosaic of the desired view was collected. An example of one photo from a calibration mosaic is included as figure 4. A map of the photo site was made using PenMap and differential GPS, with sub-meter accuracy, as shown in figure 5. The camera view point ("photo") and prominent features that appear in the photo ("cottonwood tree", "joshua tree", "lightpole", etc.) were mapped and imported into the DEM used to create the renderings. Thus, the precise camera position was used to generate the rendering, and digital images of trees were imported at the locations of the real trees mapped in the field. The rendered landscape was compared to the photo-mosaic to validate the computer model in the minds of the viewer. An example

Figure 4. Digital photograph looking north from location shown in figure 5.

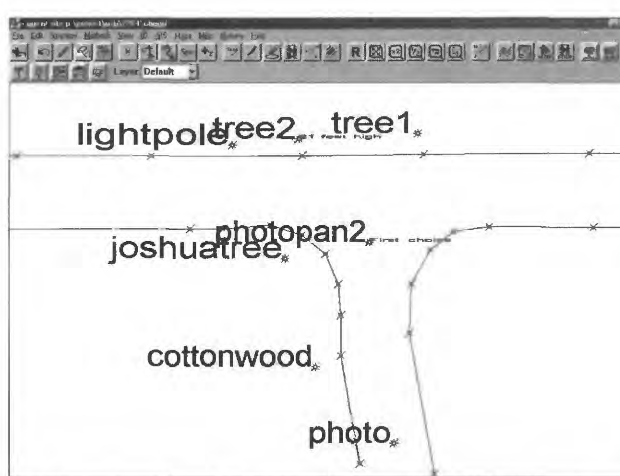

Figure 5. Digital field map of photo location shown in figure 4 and other features used to calibrate computer-rendered landscape.

calibration suite of a photo and rendering is shown in figure 6. Once calibrated, the same DEM was amended to include the components of the hypothetical future waste-rock dump. Two new renderings from the same camera view were made of the amended DEM to create a realistic view of things to come, first without and then with a buffer of trees. A truck from the photo was superimposed to show the scale of the trees in the final version of the rendering. The renderings of the future landscapes are not available for publication, but the process can be seen in the present-day landscape shown in figure 6.

The final products were posters showing a map of the area with the camera view displayed, a photo-mosaic of the true scene, the associated rendered landscape, and two renderings of the future view, with and without trees. The posters were used at a public meeting but could also have been available to the public via the Internet. In the process of developing the desired views, Condor mounted the illustrations on a secure Web site where the client could view and comment on drafts. In this way, digital field methods were fully integrated into an Internet access port. Mapping agencies will someday be expected to support Internet based interaction between field work and public in this or similar ways.

Figure 6. An example of the use of digital photography to validate a computer-modeled landscape.

CONCLUSION

Digital field mapping has come of age. Tools for digital mapping and field data collection are available for a wide range of mapping tasks, from the collection of numeric data and notes to full geological mapping capability. Various supporting technologies (GPS, laser, digital photo, analytical sensors) supplement and expand the capabilities of field geologists. Integration of digital mapping systems into an organization's mission is a challenging task during the fast-paced evolution of hardware and software. While integrators most often tout enhanced efficiency in the field, (quicker, more accurate, fewer mobilizations, etc.), there are pitfalls to this argument that can sink a budding program. Logistically, digital mapping is a more complex operation than pencil and paper methods. There are dozens of details that must work in consort (batteries, cables, back-up procedures, etc.) that require training and continued practice. The real efficiency-gain from digital geological field mapping comes from the compatibility of digital field maps and final output formats (Kramer 1998). As digitally trained professionals are only just being trained, the eventual rewards of born digital maps are still unforeseen. Digital mapping and associated technologies will make new uses for geologic information, changing the ways that state geological surveys and the USGS interact with the public.

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The U.S. Geological Survey's Revision Program for 7.5-Minute Topographic Maps

By Larry Moore

U.S. Geological Survey
Mid-Continent Mapping Center
1400 Independence Road, MS 509
Rolla, MO 65401
Telephone: (573) 308-3661
Fax: (573) 308-3652
e-mail: lmoore@usgs.gov

ABSTRACT

The 1:24,000-scale, 7.5-minute topographic quadrangle is the primary product of the U.S. Geological Survey's (USGS) National Mapping Program. This map series includes about 53,000 map sheets for the conterminous United States and is the only uniform map series that covers this area at such a large scale. The 7.5-minute mapping program lasted almost 50 years, from the mid-1940's until the early 1990's, and consisted of new mapping. New aerial photographs were taken, field control was obtained, and field-based photointerpretation was done for every quadrangle. Feature names were verified by personal contacts with local residents and local government agencies.

Various processes are used to revise these maps. Some revisions use traditional analog processes, some use digital processes; some work is done by USGS employees, some by contractors. There are four main categories of map revision: minor, basic, complete, and single edition. Minor revision is done on maps that have few changes since the last revision; it includes boundary updates and corrections of previously reported errors. Basic revision updates features from digital orthophoto quadrangles (DOQ) and aerial photographs. Contour update is an optional part of basic revision and is not often done because of the high cost. Complete revision of all layers is seldom performed because of the high cost. Single-edition revisions are done by the U.S. Department of Agriculture Forest Service using procedures similar to basic revision.

The current revision program was not designed to do replacement mapping. Most map revision is done from remote and secondary data sources, including the following:

- Geometry is controlled and some feature content interpreted from DOQ's.
- Most feature content is interpreted by using stereophotographs from the National Aerial Photography Program.
- Boundary and name information is collected from Federal databases, other maps, and State and local agencies.
- Some content may be field checked by Earth Science Corps volunteers (private citizens who donate time to do field verification work) or by State agencies participating in cooperative mapping projects.

INTRODUCTION

In 1989, the Mapping Science Committee of the National Research Council wrote that "...the primary product [of the U.S. Geological Survey (USGS) National Mapping Division (NMD)] is the 1:24,000, 7.5-minute topographic quadrangle series. This...is the only uniform map series that covers the entire area of the [continental] United States in considerable detail. The series will be completed in 1990...NMD's principal raison d'etre is changing to the equally challenging task of maintaining currency of these maps...A major ongoing revision effort, which NMD is now pursuing, is required" (National Research Council, 1990, p. 8).

The USGS produces printed maps and digital map data for all States, possessions, and territories of the United States, and Antarctica. This paper discusses only the 1:24,000- and 1:25,000-scale topographic maps in the

48 continental United States. There are 54,890 standard 7.5-minute and 7.5- by 15-minute cells in this domain.

Because the two cell sizes overlap, the number of map sheets has varied with time. At present, there are 53,336 map sheets that cover the continental United States. Both cell sizes and scales are referred to in this paper as "7.5-minute maps" or "7.5-minute quadrangles."

The 7.5-minute maps are more detailed versions of other quadrangle series that date back to the formation of the USGS in 1879 (Schwartz, 1980, p. 311). Although 7.5-minute maps were produced by the USGS as early as 1908, the effort to cover the country at this scale was a product of World War II technological advances and 1939 legislation creating a National Mapping Program (Bohme, 1989, p. 167). Initial coverage of 7.5-minute maps in the continental United States is summarized in figure 1. The program grew rapidly from 1945 through 1955, then more slowly, and peaked in 1973. In the early 1980's, it became evident that production rates were not sufficient to finish the series before the year 2000. Beginning in 1982, manuscript maps without final cartographic finishing were published (Bohme, 1989, p. 167). These were designated "provisional maps" (P-maps). A significant production increase in the mid-1980's resulted from the lower cost of provisional mapping (fig. 1). Most of the work on the 7.5-minute maps was finished by 1990, and the series was officially declared complete in 1992.

MAP REVISION PROGRAMS AND METHODS

7.5-minute maps have been revised almost from the beginning of the program, but revision numbers did not become significant until the mid-1960's (fig. 2). To speed up the revision of existing map sheets, an interim revision was introduced in 1967 (Bohme, 1989, p. 167). Commonly called photorevision, this remained the most common type of revision through the 1980's. The original map base was used as horizontal control, and new features were collected from stereophotographs without field verification. Contours usually were not revised. To show that the revision did not meet new mapping standards for control and field verification, new photorevised features were printed on the maps in purple.

With the completion of the 7.5-minute mapping program in 1992, the USGS began formulating a graphic revision plan to keep primary series maps current. Decisions

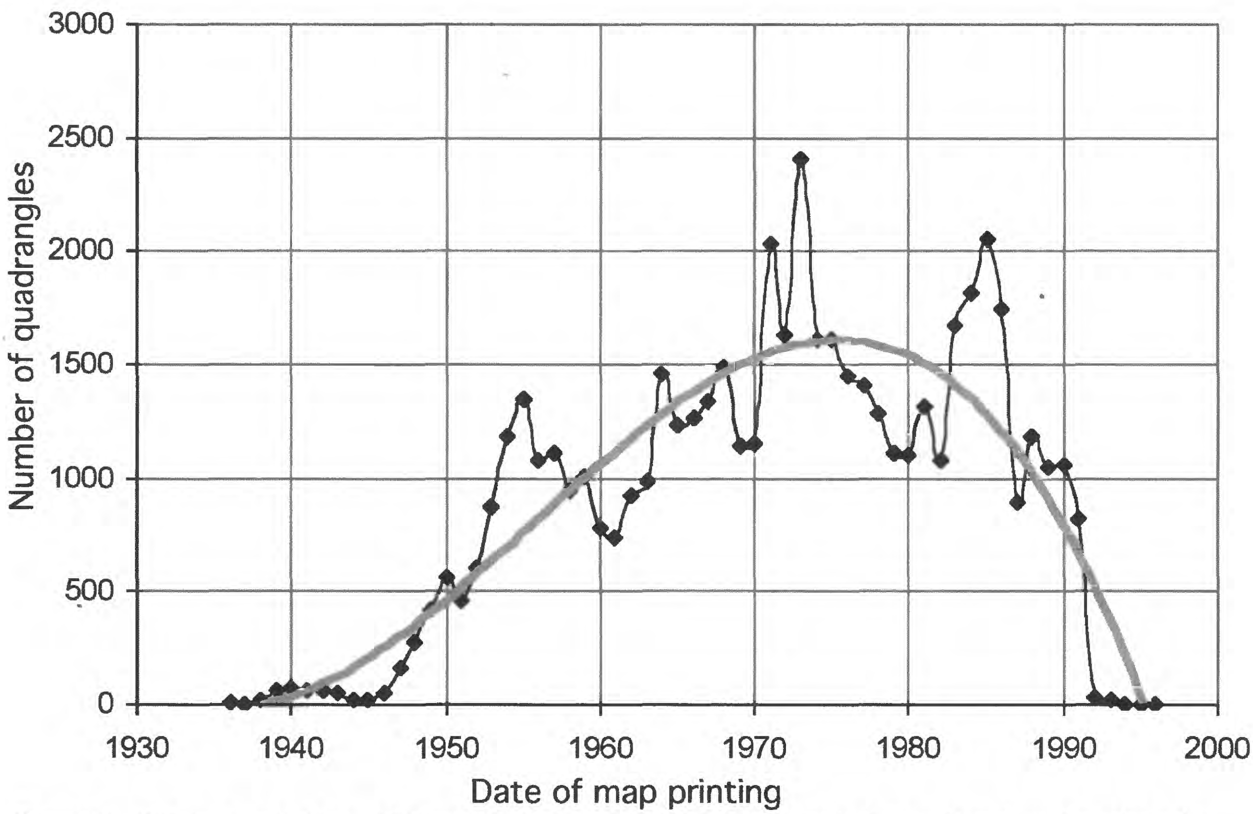


Figure 1. Original production of 7.5-minute quadrangles. Each data point is the number of quadrangles published in a particular year. Each cell is shown only once, the first time a map for the cell was made. The median date of printing is 1972. The smooth gray curve is a polynomial trendline. The data for this and the other figures in this report are from National Mapping Division databases, including the map catalog (MAPCAT) and the assignment management system (AMS).

about revising 7.5-minute quadrangles are based on user requirements, available resources, and the preferences of funding cooperators. Accuracy assessments, evaluations of existing quadrangle materials, and error reports are also considered. Two primary drivers of the NMD revision program are listed below.

- Cooperative funding from other agencies. The USGS will divide revision costs equally with other State or Federal agencies.
- A list of 5,000 "high seller" maps. These maps are judged to be most in demand and are given priority for revision work. A percentage of these maps are revised each year with or without cooperative funding.

Revision decisions are also constrained by other factors. The most important of these is the availability of recent aerial photography and digital orthophoto quadrangles (DOQ) for the quadrangle under consideration.

Figure 2 shows the overall currentness of the 7.5-minute maps at the end of 1999. The median currency date for the series as a whole is 1979, so the average 7.5-minute map is almost exactly 20 years old. The data in this figure include all photorevisions and minor revisions but not maps reprinted "as is" to replace low shelf stock. The curve falls rapidly toward zero as it approaches the year 2000, but this does not indicate that the revision program is dying. Aerial photographs and other source materials used for map revision are usually 3 to 5 years old by the time the map is published, so most maps printed in 1999 appear in the years 1994 to 1996 in figure 2.

There are currently four official types of map revision: minor revision, basic revision, complete revision, and single-edition revision. The first three are defined by USGS product standards, the fourth by an interagency agreement with the U.S. Department of Agriculture Forest Service (FS). Numbers of each type of revision produced from 1996 to 2000 are shown in figure 3.

Minor Revision

Revision candidate quadrangles are compared to recent aerial photographs to determine how much change has occurred since the last map revision. If changes are small and few in number, the map may need only minor

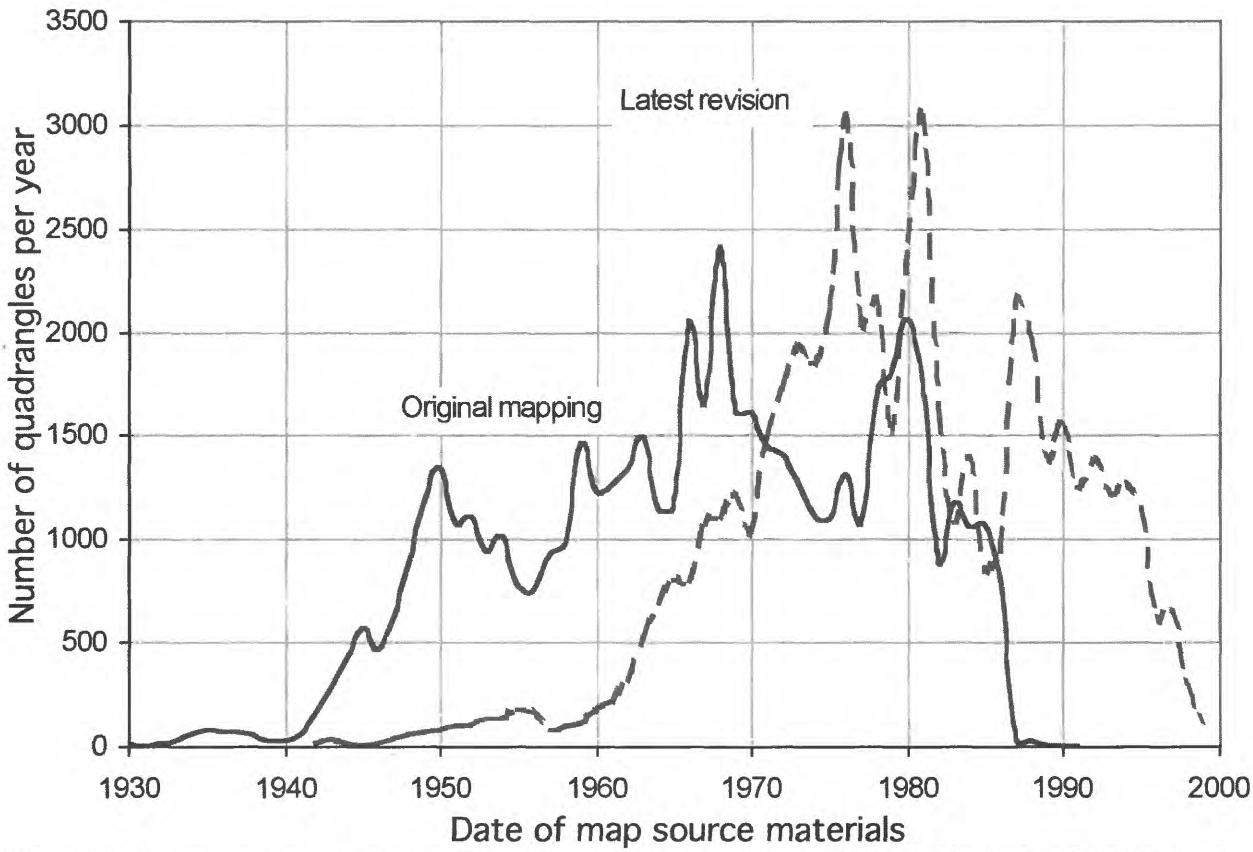
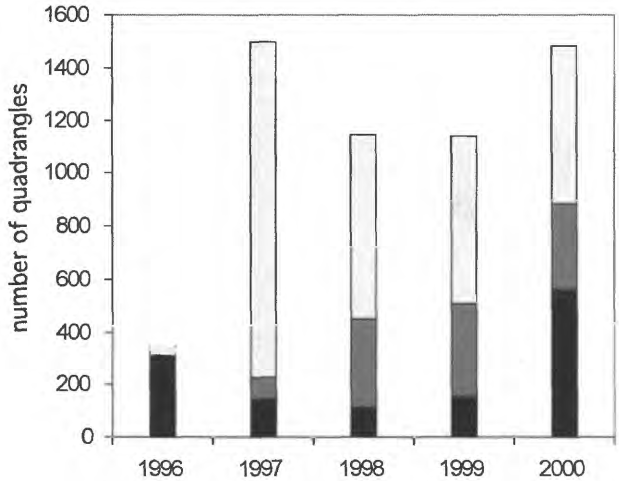


Figure 2. Currentness of revised maps compared to original maps. The solid line is identical to that in Figure 1, except it is shifted 5 years to the left to show average date of content rather than date of printing. The dashed line shows the date of content for the most recent revision of each cell. For example, 1981 is the source photography date for the most recent revision of about 3,000 quadrangles. The median currency date for original mapping is 1967; the median for latest revisions is 1979. The data include minor revisions but not maps reprinted "as is" to replace low shelf stock.



Forest Service	32	1,271	696	630	*600*
Minor		83	340	356	*323*
Basic contour			5	26	*47*
Basic	311	145	106	129	*515*
Total	343	1,499	1,146	1,141	*1,485*

Figure 3. Numbers and types of recent revisions. Basic revision and basic with contour revision are combined in the bar graph. 2000 numbers are planned, not actual. The data show the year that production work was finished; source photography dates average about 3 years earlier.

revision. Names and boundaries are updated using information from local sources and other maps. Corrections on file are made and the map collar is updated.

Basic Revision

Basic revision uses aerial photographs from the National Aerial Photography Program (NAPP) to update a subset of map features. DOQ's made from NAPP photographs are the primary data source. The DOQ's are used for horizontal position control and for feature interpretation. Stereopairs of the same NAPP photographs aid feature interpretation. In some cases, field checks may be performed by volunteers or by State cooperating agencies. Name, boundary, and collar updates are similar to minor revision. Basic revisions may or may not include contour updates.

Even though it depends almost entirely on remote sources, basic revision is not cheap. Basic revisions done with USGS Government labor in 1998 and 1999 required an average of 280 hours per quadrangle, or approximately $17,000. Although costs for contractor-produced revisions in 1999 were comparable, they are expected to decrease as contractors gain experience with USGS standards.

Complete Revision

Complete revision updates all standard feature content, including contours. Information is field checked. This is very expensive and is therefore rarely done. Only four USGS quadrangles were completely revised between 1995 and 2000. Complete revision of these four was possible because a State agency did the field verification work.

Single Edition

In 1993, the USGS and the U.S. Forest Service (FS) signed an interagency agreement to begin a joint single-edition mapping program. The content of the maps includes the features normally shown on USGS maps, with additional features required for the management of National Forest System land. Under the agreement, 7.5-minute quadrangles that contain National Forest land are revised by the FS but are printed and distributed by the USGS. There are about 10,000 7.5-minute single-edition map cells. Procedures for single-edition updates are controlled by the FS and are similar to USGS basic revision procedures. The interagency agreement allows the FS to update only the National Forest land on a quadrangle and leave the other areas of the map unrevised. In these cases, the remainder of the map is part of the USGS revision pool. The two organizations have different requirements and criteria for selecting maps for revision, so revision of forest and non-forest land is usually not concurrent.

DATA SOURCES

The current USGS revision program was not designed to do replacement mapping. Most revision work is done using remote and secondary sources, including the original map, recent aerial photographs, information from other maps, and information from other Government agencies. Following are the major sources of data.

Aerial Photographs and Digital Orthophotos

DOQ's are the most critical input to basic revision. They are made using horizontal control that is usually independent of the topographic map, and the average USGS DOQ is positionally more accurate than the average topographic quadrangle. An objective of basic revision is, therefore, to make the revised map match the DOQ. Major planimetric features, especially roads and buildings, can be collected directly from a DOQ in computer-aided drafting software systems.

DOQ's are made from NAPP photographs, and basic revision compilers also use stereopairs of the original photographs to assist with feature interpretation. The current NAPP plan calls for full coverage of the continental United States in 7 years (1997-2003). This schedule is subject to availability of funding, including State cooperative funding (U.S. Geological Survey, 1996).

It is not necessarily the case that a DOQ made from the most recent photography exists. The NAPP, the DOQ program, and the map revision program are not closely coupled; each has its own customer base and its own funding sources. Nonavailability of recent aerial photographs, a recent DOQ, or the control needed to make a DOQ can make it impossible to revise a particular map.

The photographs for the original 7.5-minute program usually had scales that range from 1:15,000 to 1:25,000. The NAPP photographs used for revision have an average scale of approximately 1:40,000. The smaller scale has some effects on the accuracy of the revision, especially on contour updates.

Other Government Agencies

The USGS depends on other agencies for some types of data, particularly boundaries. When a map is authorized for revision, requests for up-to-date boundary information are sent to Federal, State, and local government agencies. The elapsed time between requesting and receiving these data can be a significant factor in the total time required to revise a map.

State agencies participating in cooperative mapping projects may also elect to do field verification work to improve the accuracy and completeness of the map content.

Geographic Names Information System

The Geographic Names Information System (GNIS) database is the official repository of feature names for the United States. Names and feature locations are checked against the GNIS and changes are included on every topographic map revision.

Earth Science Corps

The USGS has a volunteer program that allows private citizens to contribute to the earth science mission of the agency. The Earth Science Corps is the field component of the volunteer program, and it includes an ongoing map annotation project where volunteers collect new information to be used in the National Mapping Program. As of October 1999, about 3,100 quadrangles had been assigned to 2,400 volunteers.

CONTOUR UPDATES

Elevation contour lines are the signature feature of USGS topographic maps. Much of the other information on a 7.5-minute map can be found on other types of maps, but until the recent development of airborne laser and radar ranging technologies, there were no other sources of elevation data with comparable coverage and accuracy.

The USGS map revision programs have always assumed that topography is much more stable than planimetry. A new road or subdivision disturbs the land surface slightly, but rarely is the disturbance enough to warrant major revision of contour lines with 10-, 20-, or 40-foot intervals. The current map revision program is explicitly tied to DOQ's, and contours cannot be revised from these monoscopic images.

Basic revision follows these guidelines for revising contours:

- Contours are revised only as part of joint funding agreements; that is, only when another agency is willing to share the cost. Revising contours can increase the cost of a revision by 50 to 100 percent.
- The contour overlay is not completely recompiled but rather is updated in areas of significant topographic change. The original map base is used for vertical control.
- In areas of insignificant topographic change, "logical contouring" is used to preserve registration with other features. For example, contours are squared across new roads and routed around new ponds without stereorecompilation.

Contours are revised with NAPP stereophotographs, which are usually smaller scale than the photographs used to compile the original contours. Therefore, improving the accuracy of existing contours is usually not possible except in areas of very significant surface disturbance. This is consistent with the overall objectives of the revision program, which are to maintain the horizontal and vertical accuracy of the existing map.

Most basic revisions do not include contour updates (fig. 3), which means that the topography and planimetry on the revised graphic have different currentness dates. In some cases, this leads to glaring visual artifacts, such as contour lines in large water bodies or new islands with no topography.

ACCURACY OF REVISED MAPS

The USGS originally compiled topographic maps using procedures designed to meet the National Map

Accuracy Standards (NMAS). Basic revision procedures were originally designed to retain the accuracy of the existing map but not necessarily to improve it. This objective has shifted in the last 2 years, and now the horizontal accuracy goals of basic revision are that the revised map should be at least as accurate as the previous version and that all features should match the DOQ to within at least 73 feet. Both goals are evaluated by statistically comparing the map to the DOQ.

Contours and spot elevations also were originally compiled to meet the NMAS. At present, the USGS has no testing program to systematically evaluate the vertical accuracy of either the original or revised map. When there is some external reason to believe that contours may not meet NMAS, attempts are made to evaluate the data against independent and higher order control. Significantly improving the quality of contour data is extremely difficult because of the nonavailability of large-scale aerial photographs and vertical control that is independent of the original map base.

CONCLUSIONS

Although as many as 1,500 7.5-minute quadrangles per year are being revised, none of these are complete revisions. Very few revisions include contour updates, new control, or field verification of content.

Map revision standards and procedures currently in place will be used for at least several more years. The USGS has no specific plans to return to a program of new mapping by collecting new control and doing new field verification. In order to revise a greater number of maps with available funding, topographic map revision will continue to be done with remote and secondary sources for the foreseeable future.

RELEVANT WEB SITES

For further information, please consult these web sites:

- USGS Topographic Map Information —
<http://mcmcweb.er.usgs.gov/topomaps>

- Digital Orthophoto Quads (DOQs) —
<http://mcmcweb.er.usgs.gov/status/doq_stat.html>

- National Aerial Photography Program (NAPP) —
<http://edcwww.cr.usgs.gov/napp/napp_examples.html>
<http://mcmcweb.er.usgs.gov/status/napp_stat.html>

- Geographic Names Information System (GNIS) —
<http://mapping.usgs.gov/www/gnis/>

- Earth Science Corps —
<http://interactive.usgs.gov/Volunteer/EarthScienceCorps/>

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The National Geologic Map Database: A Progress Report

By David R. Soller[1] and Thomas M. Berg[2]

[1]U.S. Geological Survey
908 National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6937
e-mail: drsoller@usgs.gov

[2]Ohio Geological Survey
4383 Fountain Square Dr.
Columbus, OH 43224
Telephone: (614) 265-6988
Fax: (614) 268-3669
e-mail: thomas.berg@dnr.state.oh.us

The Geologic Mapping Act of 1992 and its reauthorizations in 1997 and 1999 (PL106-148) require 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 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. The third phase proposes, in the long term, to develop an online, "living" database of geologic map information at various scales and resolution. The third phase is discussed in a separate paper in these proceedings.

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, 1998, 1999a, and 1999b). At the Digital Mapping Techniques '98, '99, and '00 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-1999. 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 map catalog is designed to be a comprehensive, searchable catalog of all geoscience maps of the United States, in paper or digital format. Entries to the catalog include maps published in geological survey formal series and open-file series, maps in book publications, maps in theses and dissertations, maps published by park associations and scientific societies, maps published by other agencies, and publications that do not contain a map but instead provide a geological description of an area (for example, a state park). The catalog now contains a record for each of nearly 26,000 map products. Essentially 100% of all USGS maps have been recorded in the catalog, and in the past year emphasis shifted to assist the State geological surveys to enter all other maps into the catalog. By the date of the DMT'00 meeting, geological surveys in eight states (Arizona, Illinois, Minnesota, Nevada, New York, Ohio, Oklahoma, and West Virginia) were entering map records, as well as one University (Stanford); significantly more participation is anticipated in the coming months. [Note: as of early September, 2000, a total of 20 states were participating; the newly-contributing states were Arkansas, California, Colorado, Delaware, Florida, Kansas, Nebraska, Pennsylvania, South Dakota, Vermont, Washington, and Wyoming.] Web usage statistics indicate since entry of all USGS maps a clear increase in multiple visits to the site per month. This suggests the site is becoming a more useful resource, and additional increases in use are expected as the state geological survey maps are entered into the catalog.

Numerous enhancements were made this year to software and hardware, which is anticipated to increase the useability of the search engine and the Search Results pages, and to decrease the response time to the Web user. Availability of each USGS product is now tracked, and if the product is out-of-stock or out-of-print, users are directed to a list of depository libraries. New search criteria include product publisher, date of publication (specific or a range), and a map scale (specific or a range).

Geologic Names Lexicon

The searchable, on-line, geologic-names lexicon ("GEOLEX") now contains roughly 90% of the geologic names found in the most recent listing of USGS-approved geologic names (published in 1996 as USGS Digital Data Series DDS-6, revision 3) and is estimated to contain roughly 75% of all geologic names in the United States. Prior to loading into GEOLEX, the information on DDS-6 was consolidated, revised, and error-corrected. In the past year, work focused on resolving name conflicts and adding reference summary and other information for each entry. Work remaining includes incorporating geologic names not found on DDS-6 but recorded in the geologic names card catalog at USGS Headquarters, and incorporating names approved by the State geological surveys but not yet in the USGS records. GEOLEX is intended to be the comprehensive, authoritative listing of approved geologic names, 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 that will be introduced later this year.

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 was developed and contains projects active in 1998. The database will be updated later this year, and a publication prepared that explains its content.

PHASE TWO

Most efforts related to phase two have been directed toward the development of standards and guidelines needed to help the USGS and state geological surveys 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 to providing map catalog users with access to online products.

Standards Development

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

Geologic Map Symbolization

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 in 1996 reviewed by the AASG, USGS, and Federal Geographic Data Committee (FGDC). It 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 then was prepared as a proposed Federal standard, for consideration by the FGDC. The draft was, in late 1999 through early 2000, considered and approved for public review by the FGDC and its Geologic Data

Subcommittee. The document was released for public comment within the period May 19 through September 15, 2000 (see <http://ncgmp.usgs.gov/fgdc_gds/mapsymb/> for the document and information about the review process). This standard is described in some detail in a separate paper in these Proceedings (Soller and Lindquist).

Digital Mapping

The Data Capture Working Group has coordinated four 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 Lexington, Kentucky, and hosted by the Kentucky Geological Survey, was attended by 98 representatives of 41 state, federal, and Canadian agencies and private companies. The workshop proceedings are published (Soller, 1997, 1998, 1999, and this volume) and served on-line (<http://ncgmp.usgs.gov/pubs/of97-269>; <http://pubs.usgs.gov/openfile/of98-487>; <http://pubs.usgs.gov/openfile/of99-386>, and <http://pubs.usgs.gov/openfile/of00-325>. 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 was developed by the AASG/USGS Data Information Exchange Working Group and presented for technical review at a special session of the Digital Mapping Techniques '99 workshop (Soller and others, 1999). The revised document (entitled "Proposed Guidelines for Inclusion of Digital Map Products in the National Geologic Map Database") is now under review by 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

State and USGS collaborators on the NGMDB continue to serve as representatives to the North American Data Model Steering Committee (NADMSC), assisting in the process of developing, refining, and testing the North American Geologic Map Data Model. The NADMSC has now formed various technical teams to conduct specific tasks within a one-year period, and longer time-frames. If interested, please visit the NADMSC web site, <http://geology.usgs.gov/dm/>. More information is provided in a separate paper in these Proceedings.

Access to Online Products

Through searches of the NGMDB map catalog, users now can be directed to web sites for perusal of online products. This enhancement is now available for USGS products served on USGS Regional Publications Servers, and for metadata served on the USGS Clearinghouse node. At this time, more than 330 links exist to online map products and their metadata.

FURTHER INFORMATION

Separate discussions of 1) the public review of the geologic map symbolization standard; 2) the NGMDB Phase 3 activities; 3) the NGMDB Geologic Names Lexicon; and 4) the North American Geologic Map Data Model are available in these Proceedings. Please also refer to the NGMDB project information web site, <http://ncgmp.usgs.gov/ngmdbproject/>, for more current information.

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GEOLEX—The National Geologic Map Database's Geologic Names Lexicon

By Nancy R. Stamm, Bruce R. Wardlaw, and David R. Soller

U.S. Geological Survey
926A National Center
Reston, VA 20192
Telephone: (703) 648-4317
Fax: (703) 648-6953
e-mail: nstamm@usgs.gov

The U.S. Geological Survey, Geologic Names Committee (GNC) has since the late 1800's documented and maintained a catalog of established and revised geologic units of the U.S., its possessions, and territories. The GNC has published several U.S. geologic names lexicons (Appendix 1) at regular intervals as a means of keeping the geologic profession informed on changes and current status of geologic classifications and nomenclature found in the published literature. During the past hundred years, record keeping of geologic nomenclature has evolved from handwritten index cards into the present-day, web-interfaced relational database called GEOLEX, which is available at <http://ngmdb.usgs.gov/Geolex/geolex_home>.

The USGS geologic names lexicon, GEOLEX, a component of the National Geologic Map Database (<http://ngmdb.usgs.gov>), is a compilation of geologic names introduced into the literature from 1813 to the present for the U.S., its possessions and territories, and bordering areas of Canada and Mexico. GEOLEX is under construction; it currently contains detailed and general information for 16,005 geologic names compiled from Mac Lachlan, M.E., and others (1996), and comprises approximately 75% of the total number of documented geologic names in the GNC index card catalog. We are now adding the remaining geologic names to the database and updating the database with recently-named and revised geologic units that are recognized by the state geological surveys and the USGS.

HISTORY

The USGS Geologic Names Committee was established in the late 1800's, under the leadership of Major J.W. Powell, Director of the Survey. Its primary duties were to develop principles of rock classification and rules of stratigraphic nomenclature, and to review manuscripts and geologic maps for the purpose of maintaining uniformity in the U.S. National Geologic Atlas Folios. In the early 1900's, these principles of rock classification and rules of stratigraphic nomenclature were adopted by the USGS as standards for all formal series publications. The USGS Geologic Names Committee secretary, Grace Wilmarth, meticulously documented and maintained a catalog of the geologic nomenclature of the U.S., though it was not until 1938 that the first extensive U.S. geologic names lexicon was published, as USGS Bulletin 896 (Wilmarth, 1938).

In 1961, the USGS Geologic Names Committee established regional offices in Reston, Virginia (headquarters for the USGS eastern region), Denver, Colorado (central region), and Menlo Park, California (western region) (Fig. 1). Each office reviewed manuscripts to determine compliance with rules of stratigraphic nomenclature, and maintained separate catalogs of geologic nomenclature for specific geographic areas (with the exception of the Reston office, which continued to maintain a National dataset).

With the onset of computer technologies in the 1960's, geologic nomenclature data was entered from the regional Geologic Names Committee card catalogs into a basic spreadsheet-style format and published, as USGS Bulletin 1535 (Swanson and others, 1981). This format was based on recommendations of the American Association of Petroleum Geologists, Committee on Stratigraphic Coding (1967), and is still in use today, although since then many other formats and programming methods have been tried and subsequently discarded by the USGS.

In 1996, the most extensive U.S. geologic names lexicon was released as "Stratigraphic nomenclature databases for the United States, its possessions and territories", USGS Digital Data Series DDS-6 (Mac Lachlan and others, 1996). It consists of 3 regional databases (all called

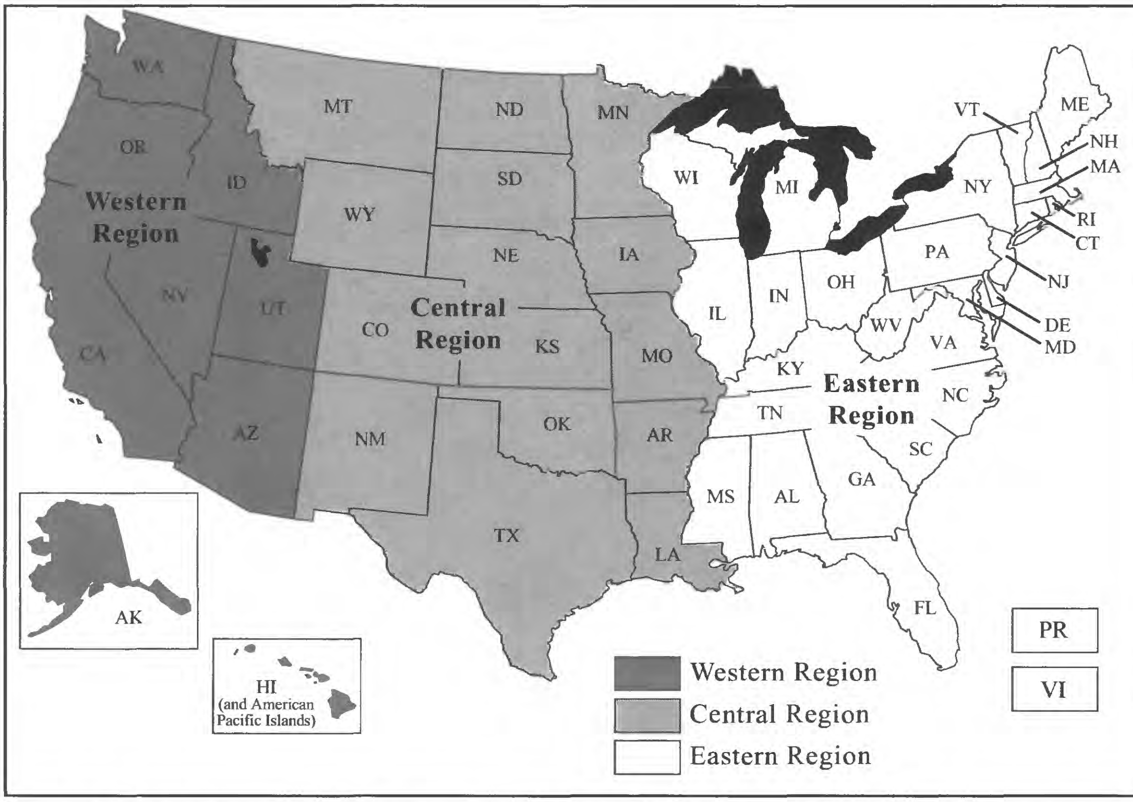


Figure 1. Map showing generalized areas covered by the USGS Eastern, Central, and Western regional Geologic Names Committee offices from 1961-1995.

GNULEX), and a concise National database (GEONAMES). The regional GNULEX databases are text-formatted in the style much like the original U.S. geologic names lexicon of Wilmarth (1938). In addition to general information about the geologic name, age, and geographic extent of the unit, these databases include bibliographic references, and synopses of data pertaining to the establishment or revision of the geologic unit compiled from published literature. The National GEONAMES database is spreadsheet-formatted in a style modified from the AAPG-Committee on Stratigraphic Coding (1967) and USGS Bulletin 1535 (Swanson and others, 1981).

During administrative reorganization and staff reductions in 1995, the USGS Geologic Names Committee was restructured and its scope of activities was reduced. The remnants of the Committee were reorganized in the Reston, Virginia offices of USGS. As a result, it was no longer necessary for the GNC to maintain four separate datasets. Also, there was a demand to develop the geologic names lexicon into a format readable by various computer platforms and technologies; further, the new lexicon needed to be easily updated and relatively inexpensive to maintain.

In 1997, we began the task of combining the four databases from USGS Digital Data Series DDS-6 into a single database (GEOLEX) using Microsoft Access. This database is then converted to an Oracle database and connected via scripts to the web-based search engine. GEOLEX data initially was compiled from the GNULEX databases, starting with the eastern region and moving west (Fig. 1). Data from the GEONAMES database was added to GEOLEX last, to fill in data missing from the GNULEX databases. Although its format is obviously more appropriate for database design than the regional GNULEX databases, the data in GEONAMES was not considered inclusive enough for the greater geologic community to effectively research the origin, definition and description, and publication history of geologic units in the U.S.

Today, the USGS Geologic Names Committee continues to review manuscripts, and document and maintain a catalog of geologic nomenclature for the U.S., its possessions, and territories. These data are added to GEOLEX on a regular basis and we are preparing GEOLEX for USGS Director's approval as a "standing database".

THE GEOLEX DATABASE

Data fields in GEOLEX that are of interest to the user include: usage of the geologic name, geologic age, geologic province, areal extent, type locality, publication history, and subunits. Most of the data was compiled into GEOLEX by the "cut and paste" method, from the regional GNULEX databases. During this process, duplicate data between the regional databases was noted and deleted. For some geologic names included in multiple databases, information pertaining to the name's establishment and revision varied, and so during compilation of GEOLEX, the information from these source databases was synthesized.

The usage, age assignment, geographic area and geologic province allocation, and subunits for geologic units reported on by USGS authors in either USGS or outside formal publications are denoted with an asterisk. Geologic name usage, age, geographic and geologic extent, and subunits not denoted with an asterisk have been published by State Survey and other non-USGS scientists.

Geologic Names Usage

As a by-product of methodological differences in regional Geologic Names Committee data entry, the accepted usage for each geologic unit (e.g., Middendorf Formation) in GEOLEX varies in style between regions of the U.S. For geologic units reported on in the eastern region (Fig. 1), each name usage is accompanied by a list of states in which this usage has been documented (e.g., "Middendorf Formation (SC*, NC*, GA*)"). Usage information for geologic units occurring in the central and western U.S. (Fig. 1) was not recorded by these regional GNCs, and so, for GEOLEX, this information was compiled by combining the "unit name" and "rank" fields from the regional GNULEX databases. These names now are being checked for accuracy, and we are adding the list of states in which this usage has been documented. Usage of geologic names that are not in compliance with the rules of stratigraphic nomenclature are noted with a slash (/). The statement "No current usage" implies that the name has been abandoned or has fallen into disuse. Former usage and the replacement name (if known) are given in parentheses ( ).

Geologic Age

The geologic age(s) for units described in GEOLEX may be searched by Era, Period (System), and Epoch (Series). The geologic time scale used for the Phanerozoic divisions has been modified from Haq and van Eysinga (1987), Harland and others (1989), and Hansen (1991). The Precambrian divisions were derived from The Museum of Paleontology (University of California at Berkeley) web site (<http://www.ucmp.berkeley.edu/precambrian/precambrian.html>).

Geologic Province

The geologic provinces listed for Phanerozoic units have been updated to follow the geologic provinces code map of Meyer and others (1991). For Precambrian units occurring in the Western Interior U.S., Mac Lachlan and others (1996, Overview) noted "... The application of province and basin names used to show the extent of Phanerozoic units is not suitable for Precambrian units of the Western Interior region. The boundaries selected for the Precambrian regions based on the advice of J. C. Reed, P. K. Sims, J. E. Harrison, Z. E. Peterman, and M. R. Reynolds of the USGS generally follow the features shown on the Precambrian geology map of Reed (1987, fig. 1)..." The Precambrian region names used and their boundaries of Mac Lachlan and others (1996) apply only to units occurring in the Western Interior U.S. Eastern regional provinces include Mesozoic basins (for the Newark Supergroup units). "Caribbean region" encompasses Puerto Rico and the U.S. Virgin Islands (Mac Lachlan and others, 1996).

Areal Extent

Areal extent for each geologic unit is provided by GEOLEX. States are listed by the U.S. Postal Service 2-letter abbreviation. For units that occur outside of the United States, the following abbreviations are used: CN (Canada), AT (Alberta), BC (British Columbia), MB (Manitoba), NW (Northwestern Territories), ON (Ontario), SK (Saskatchewan), YT (Yukon Territory); MX (Mexico); AS (American Samoa), CI (Caroline Islands), GU (Guam), MR (Mariana Islands); PR (Puerto Rico); VI (Virgin Islands).

Type Locality

For each geologic unit, the type section, locality, and/or area (if known) is given as stated by the author(s), or is taken from pre-1996 U.S. geologic names lexicons (Appendix 1). Derivation of name (if known) also is given. The statement "Not evaluated to date" means that the original reference has not yet been evaluated for this database.

Publication History

The publication history is a listing of cited references to publications that have had a significant impact on the definition or revision of a geologic name. Generally, these cited references are accompanied by the modification (Appendix 2) made to the unit (e.g., "Revised; Age modified; Biostratigraphic dating (Gohn, 1992)") and are listed in chronological order. However, as a by-product of methodological differences in regional Geologic Names Committee data entry and, therefore, in source database format, the publication history of geologic units is not formatted consistently throughout GEOLEX at this time. But, to the extent possible given time constraints, most of the citations were collated from the source databases and are listed in chronological order. The statement "Not evaluated to date" means that the original reference has not yet been evaluated for this database.

Subunits

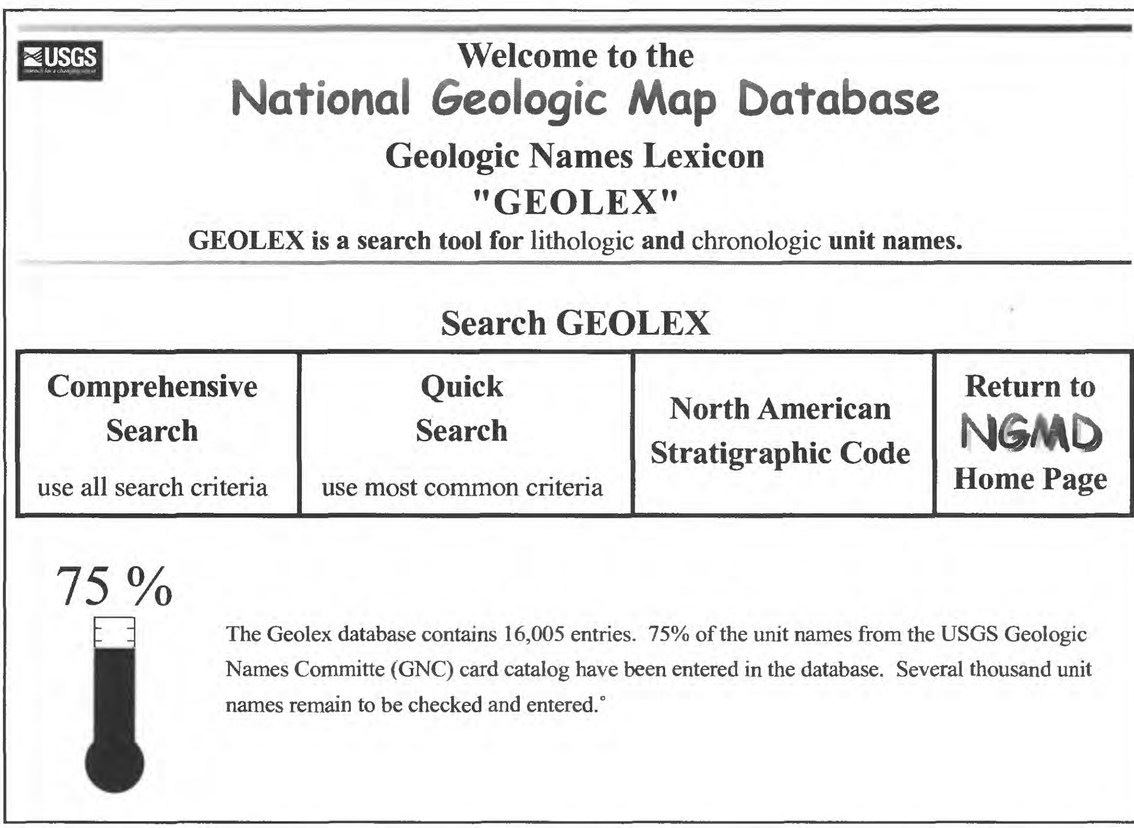
Subunits (if known) are given and are generally followed by their geographic extent in parentheses ( ).

USING GEOLEX

The GEOLEX home page <http://ngmdb.usgs.gov/Geolex/geolex_home> (Fig. 2) provides links to:

- the comprehensive search page, containing all searchable data fields (Fig. 3a);
- the quick search page, containing most commonly used data fields (Fig. 3b); and
- a link to the North American Commission on Stratigraphic Nomenclature, North American Stratigraphic Code <http://www.agiweb.org/nacsn/code2.html> (Fig. 4), which was graciously provided by the American Geological Institute. [A paper copy of the North American Stratigraphic Code can be ordered from AAPG for $3.00. The North American Commission on Stratigraphic Nomenclature is currently revising the North American Stratigraphic Code and, upon release of the Draft revision, the GEOLEX Web site will provide access to this document, for public review and comment.]

Upon using the comprehensive or quick search page (Fig. 3) to conduct a search of GEOLEX, the search results page (Fig. 5) is displayed. The results page contains general information about the geologic name. The



http://ngmdb.usgs.gov/Geolex/geolex_home.html

Figure 2. GEOLEX home page.

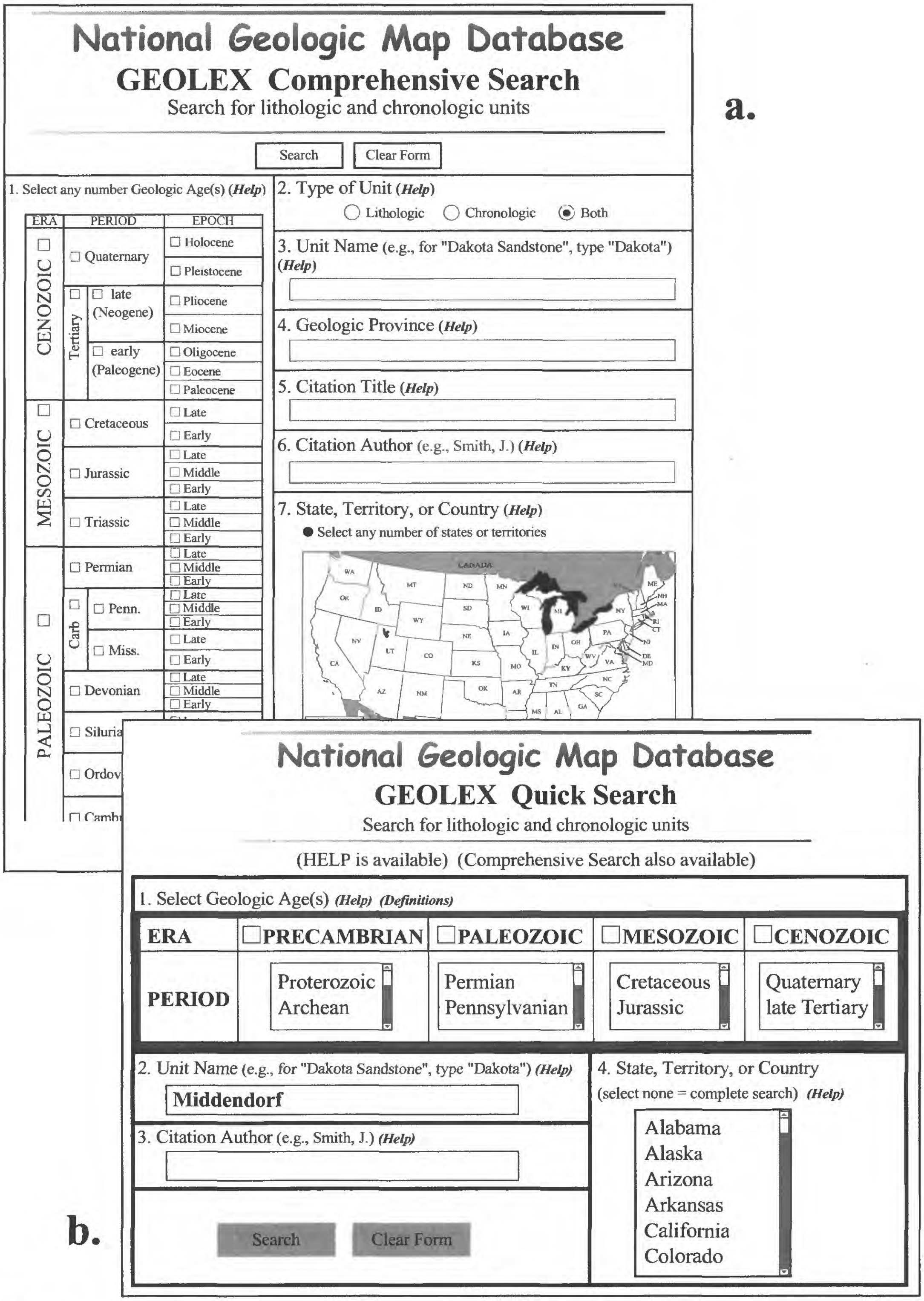


Figure 3. (a). GEOLEX comprehensive search page. (b). GEOLEX quick search page.

NORTH AMERICAN STRATIGRAPHIC CODE

The North American Commission on Stratigraphic Nomenclature

Reprinted in July, 1983
from
The American Association of Petroleum Geologists Bulletin
Volume 67, Number 5 (May, 1983)

NACSN 1983 CODE
http://www.agiweb.org/nacsn/code2.html

Figure 4. North American Stratigraphic Code.

citation summary page (Fig. 6) is linked from the search results page through the "publication history" field. By selecting the "History" link (Fig. 5), the user can view the bibliographic citations and synopses of information compiled from the publications.

The information displayed on these citation summary pages (Fig. 6) were extracted from the regional GNULEX databases using Perl scripts and cut-and-paste methods to transfer appropriate information to GEOLEX data fields. For the 16,005 geologic names in GEOLEX, there are approximately 30,000 synopses pertaining to the establishment or revision of specific geologic units. These synopses were compiled from approximately 8500 publications.

The "citation summary" page (Fig. 6) includes, for most references cited under "History" in Fig. 5, the following: full bibliographic citation, usage of geologic name in the publication, type of modification (Appendix 2), geologic province, dominant lithology, and a brief synopsis of information pertaining to the geologic unit. The synopses are compiled from the publication, and can include: reason(s) for establishment or modification, type locality or reference section description, study area locality description, geologic setting, lithologic description, thickness of unit, unit correlations, geologic contacts, biostratigraphic and isotopic determinations, geologic age assignment, historical background, and inclusion of correlation charts and maps in the publication.

We have updated the bibliographic citations to maintain uniformity. But, the geologic provinces listed on the citation summary page (Fig. 6) have not been updated from Mac Lachlan and others (1996), and thus follow either Meyer (1974) or Meyer and others (1991). Dominant lithologies are listed for publications where the geologic unit is named, and in some cases, where the geologic unit is redescribed, redefined, or mapped.

PLANNED ENHANCEMENTS

During Fall and Winter 2000, we will be adding publicly-accessible input forms to the GEOLEX database web pages. These will allow authors to enter information on names they have newly established or revised through publication in a formal series or journal. Once the authors have filled in the forms, the data will be reviewed by the USGS Geologic Names Committee to determine compliance with the rules of stratigraphic nomenclature (North American Stratigraphic Code) and then, upon approval, added to the GEOLEX database. Fields included in the input form for newly established names (Fig. 7) and for modifications to existing names (Fig. 8) follow that of the North American Commission on Stratigraphic Nomenclature (1983).

The USGS Geologic Names Committee also will be adding publicly-accessible input forms to allow authors to reserve new geologic names for future publication (Fig. 9). Once the authors have filled in the forms, the names will be checked to ensure that they are not already in use.

From time to time throughout its existence, the USGS Geologic Names Committee has solicited the advice and assistance from State Survey geologists on the preferred usage of geologic nomenclature in their state. When we assembled the data from the regional databases into one database and analyzed it, we concluded that we are not adequately depicting current State Survey geologic nomenclature. It has, therefore, been resolved that each State Survey has the final authority on stratigraphic nomenclature within their state, provided that it complies with the North American Stratigraphic Code; the USGS Geologic Names Committee plans to work with State Survey geologists to resolve any discrepancies.

National Geologic Map Database

GEOLEX database

New Search | Refine Search

Geologic Unit Name: Middendorf

Usage:
Middendorf Formation (SC*,NC*,GA*)
Middenforf Formation of Lumbee Group (SC,NC)

Age:	Geologic Province:	Areal Extent:
Cretaceous, Late* Santonian, middle*	Atlantic Coast basin* South Georgia sedimentary province*	GA* NC* SC*

Type Locality:
Named for exposures near Middendorf, Chesterfield Co., SC (Sloan, 1904).

History:
Named (Sloan, 1904). Overview (Sloan, 1907). Abandoned (Cooke, 1936). Overview (Wilmarth, 1938). Reinstated (Bell and others, 1974). Geographically extended into GA (Newell and others, 1980). Assigned to Lumbee Group (Swift and Heron, 1984). Revised, age modified, biostratigraphic dating (Gohn, 1992). Biostratigraphic dating (Gohn and others, 1992). Overview (Fallaw and Price, 1992).

Note: For more information, contact Nancy Stamm (nstamm@usgs.gov).

Asterisks (*) indicate usage by the U.S. Geological Survey.

"*No current usage*" implies that a name has been abandoned or that it has fallen into disuse. Former usage, and, if known, replacement name given in parentheses ( ).

Slashes (/) indicate unit name usage violates the 1983 North American Stratigraphic Code. This violation may be explained within brackets [ ].

Figure 5. GEOLEX search results page.

Summary of Citation: Middendorf

Publication:

Gohn, G.S., 1992, Revised nomenclature, definitions, and correlations for the Cretaceous formations in USGS-Clubhouse Crossroads #1, Dorchester County, South Carolina: U.S. Geological Survey Professional Paper 1581, 39 p.

Usage in Publication:

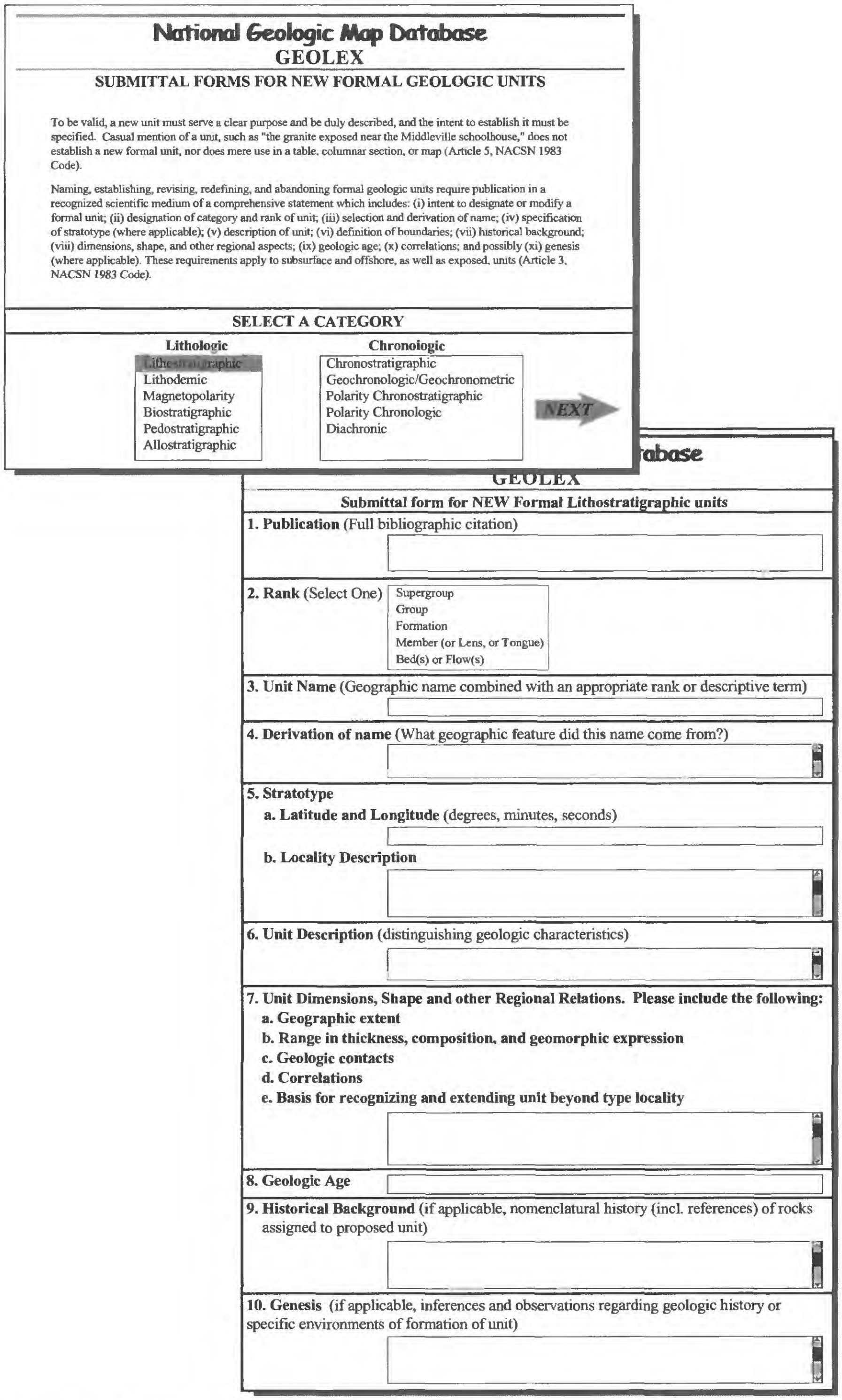
Middendorf Formation*

Modification(s):	Geologic Province:	Dominant Lithology:
Revised Age modified Biostratigraphic dating	Atlantic Coast basin	

Summary:

The Cape Fear Formation in the Clubhouse Crossroads drill core revised to include part of section previously assigned to Cape Fear and virtually all of section previously assigned to Middendorf Formation. Beech Hill (new) and Clubhouse (new) Formations assigned to sediments of lower and middle part of former Cape Fear. Middendorf in core is revised to include section between revised Cape Fear below and newly defined Shepherd Grove Formation above. Previous assignment of this interval to Black Creek Group is refuted as is correlation of interval now assigned to Middendorf with outcropping Black Creek Group elsewhere. Reasons are that alternating coarse feldspathic sands and reddish clays originally assigned to Middendorf at Clubhouse Crossroads core (Gohn and others, 1977) have been correlated with sediments assigned to Cape Fear in other holes located updip from Clubhouse Crossroads core. Lithologic similarity of this unit with outcropping Cape Fear supports correlation. Therefore, section originally assigned to Middendorf at Clubhouse Crossroads is removed from Middendorf and reassigned to Cape Fear. Cape Fear in drill core is redefined as alternating yellowish-gray, red, and brown, noncalcareous and sparingly calcareous clays and tan feldspathic sands. Middendorf in drill core is redefined as light- to medium-gray, well-sorted, coarse-grained sands and dark lignitic clays. Late Cretaceous (middle Santonian) age is based on information from a variety of fossil groups. Presence of calcareous nannofossil CALCULITES OBSCURUS in underlying Cape Fear Formation requires upper part of Cape Fear and Middendorf to be no older than Santonian (zone NC17); in addition, oyster OSTREA CRETACEA, which occurs in upper part of Middendorf in the core, is restricted to Santonian (Sohl and Owens, 1991), and presence of nannofossil EPROLITHUS FLORALIS in overlying Shepherd Grove Formation requires lower part of Shepherd Grove and Middendorf to be no younger than Santonian; Valentine (1984) reports, but does not itemize, a "rich Santonian nannofossil assemblage" from 1757 ft in core.

Figure 6. GEOLEX citation summary page.



National Geologic Map Database
GEOLEX
SUBMITTAL FORMS FOR NEW FORMAL GEOLOGIC UNITS

To be valid, a new unit must serve a clear purpose and be duly described, and the intent to establish it must be specified. Casual mention of a unit, such as "the granite exposed near the Middleville schoolhouse," does not establish a new formal unit, nor does mere use in a table, columnar section, or map (Article 5, NACSN 1983 Code).

Naming, establishing, revising, redefining, and abandoning formal geologic units require publication in a recognized scientific medium of a comprehensive statement which includes: (i) intent to designate or modify a formal unit; (ii) designation of category and rank of unit; (iii) selection and derivation of name; (iv) specification of stratotype (where applicable); (v) description of unit; (vi) definition of boundaries; (vii) historical background; (viii) dimensions, shape, and other regional aspects; (ix) geologic age; (x) correlations; and possibly (xi) genesis (where applicable). These requirements apply to subsurface and offshore, as well as exposed, units (Article 3, NACSN 1983 Code).

SELECT A CATEGORY

Lithologic	Chronologic
Lithostratigraphic	Chronostratigraphic
Lithodemic	Geochronologic/Geochronometric
Magnetopolarity	Polarity Chronostratigraphic
Biostratigraphic	Polarity Chronologic
Pedostratigraphic	Diachronic
Allostratigraphic	

NEXT

GEOLEX
Submittal form for NEW Formal Lithostratigraphic units

1. **Publication** (Full bibliographic citation)

2. **Rank** (Select One) Supergroup / Group / Formation / Member (or Lens, or Tongue) / Bed(s) or Flow(s)

3. **Unit Name** (Geographic name combined with an appropriate rank or descriptive term)

4. **Derivation of name** (What geographic feature did this name come from?)

5. **Stratotype**
   - a. **Latitude and Longitude** (degrees, minutes, seconds)
   - b. **Locality Description**

6. **Unit Description** (distinguishing geologic characteristics)

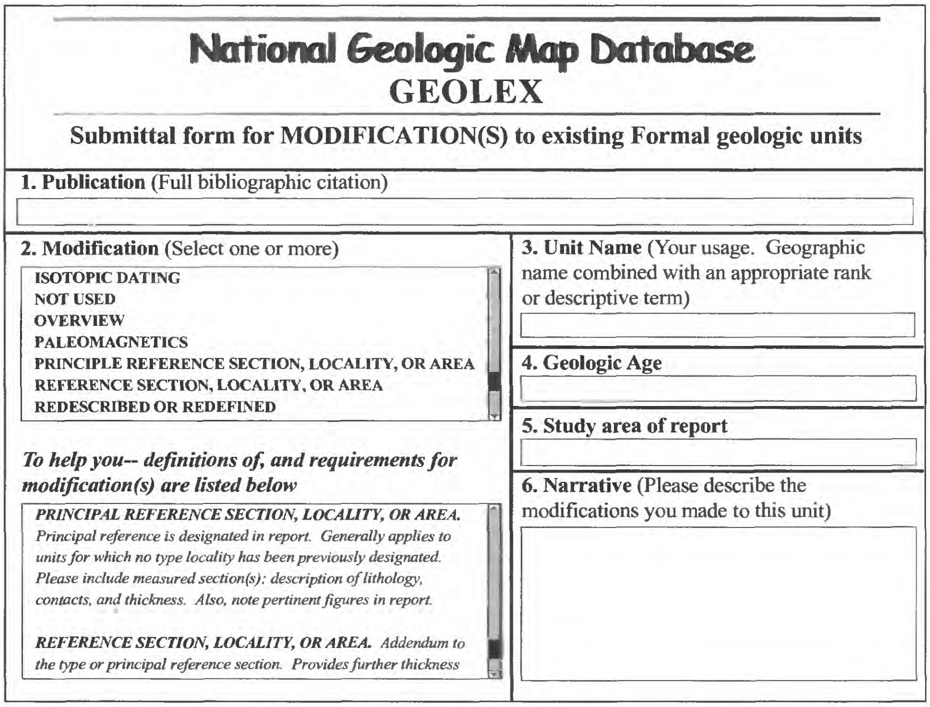
7. **Unit Dimensions, Shape and other Regional Relations. Please include the following:**
   - **a. Geographic extent**
   - **b. Range in thickness, composition, and geomorphic expression**
   - **c. Geologic contacts**
   - **d. Correlations**
   - **e. Basis for recognizing and extending unit beyond type locality**

8. **Geologic Age**

9. **Historical Background** (if applicable, nomenclatural history (incl. references) of rocks assigned to proposed unit)

10. **Genesis** (if applicable, inferences and observations regarding geologic history or specific environments of formation of unit)

Figure 7. Proposed GEOLEX input form for newly established names.



National Geologic Map Database

GEOLEX

Submittal form for MODIFICATION(S) to existing Formal geologic units

1. Publication (Full bibliographic citation)

2. Modification (Select one or more)

ISOTOPIC DATING
NOT USED
OVERVIEW
PALEOMAGNETICS
PRINCIPLE REFERENCE SECTION, LOCALITY, OR AREA
REFERENCE SECTION, LOCALITY, OR AREA
REDESCRIBED OR REDEFINED

To help you-- definitions of, and requirements for modification(s) are listed below

PRINCIPAL REFERENCE SECTION, LOCALITY, OR AREA. *Principal reference is designated in report. Generally applies to units for which no type locality has been previously designated. Please include measured section(s); description of lithology, contacts, and thickness. Also, note pertinent figures in report.*

REFERENCE SECTION, LOCALITY, OR AREA. *Addendum to the type or principal reference section. Provides further thickness*

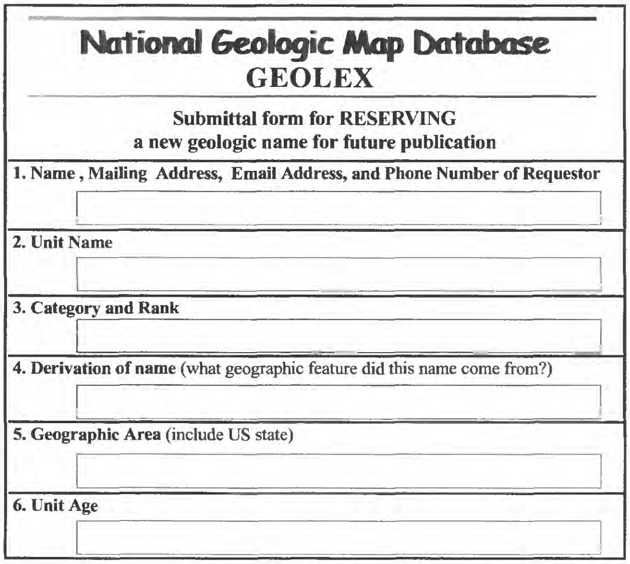
3. Unit Name (Your usage. Geographic name combined with an appropriate rank or descriptive term)

4. Geologic Age

5. Study area of report

6. Narrative (Please describe the modifications you made to this unit)

Figure 8. Proposed GEOLEX input form for modifications to existing names.



National Geologic Map Database

GEOLEX

Submittal form for RESERVING a new geologic name for future publication

1. Name , Mailing Address, Email Address, and Phone Number of Requestor

2. Unit Name

3. Category and Rank

4. Derivation of name (what geographic feature did this name come from?)

5. Geographic Area (include US state)

6. Unit Age

Figure 9. Proposed GEOLEX input form to reserve new geologic names for future publication.

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APPENDIX 1.

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APPENDIX 2.

Glossary of Modifications* to Geologic Names

1. **ABANDONED.** Author(s) provides sufficient justification to abandon name and make recommendations for replacement name(s) in accordance with the NACSN 1983 Code. Please include reasons for abandonment and replacement names. Not used for restriction of areal extent. (ALSO SEE "NOT USED" AND "AREAL LIMITS")
2. **ADOPTED (USGS).** A USGS author may adopt a unit name for USGS usage by citation [i.e., explicit statement of intent to name a new unit or adopt the previously published unit usage of another (non-USGS) author] in a formal publication. It is the author's responsibility to determine whether the unit, as previously defined (by a non-USGS author), is properly defined according to NACSN 1983 Code; if it has not been sufficiently defined, additional information must be included to conform with the NACSN and USGS standards.
3. **AGE MODIFIED.** Age of unit has been changed or refined either regionally or locally. Please include evidence for age change. (ALSO SEE "BIOSTRATIGRAPHIC DATING" AND "ISOTOPIC DATING")
4. **AREAL LIMITS.** Geographic extension or restriction of unit on surface and/or in subsurface. Also used when report discusses known areal extent of unit. Please note scale and includsion of geologic or isopach maps in report.
5. **BIOSTRATIGRAPHIC DATING.** Age determination of unit based on recognition of index fossils or biozonal assignment. Does not include mere mention of fossils. Please include fossil types. (ALSO SEE "AGE MODIFIED")
6. **ISOTOPIC DATING.** Numerical age of unit determined from isotopic ratios, fission tracks, and other age-related phenomena. Please include dating technique and error values. (ALSO SEE "AGE MODIFIED")
7. **NOT USED.** Unit name has been rejected (but not formally abandoned) by author, in preference to another name. Please include reason for non-use, if stated in report. (ALSO SEE "ABANDONED")
8. **OVERVIEW.** Report includes detailed local or regional information (i.e., measured sections, source, environment of deposition, thickness of unit). Also used to indicate continued use of an old, but seldom used name. Please note inclusion of geologic, isopach, or areal extent maps; cross sections; correlation charts or history-of-use charts; or other pertinent figures in report.

9. **PALEOMAGNETICS.** Determinations based on remnant-magnetic properties; most commonly polarity (normal or reversed). Please include dipole-field-pole position, non-dipole component, and field intensity if possible.
10. **PRINCIPAL REFERENCE (SECTION, LOCALITY, OR AREA).** Principal reference is designated in report. Generally applies to units for which no type locality has been previously designated. Please include measured section(s); description of lithology, contacts, and thickness. Also, note pertinent figures in report. (ALSO SEE "REFERENCE")
11. **REFERENCE (SECTION, LOCALITY, OR AREA).** Addendum to the type or principal reference section. Provides further thickness and lithological information. Please include description of rocks at reference section(s). Also, note pertinent figures in report. (ALSO SEE "PRINCIPAL REFERENCE").
12. **REDESCRIBED OR REDEFINED.** Unit composition is changed due to geochemical analyses, detailed mapping, etc. Descriptive lithic or rank term changed because of change in dominant lithology. (ALSO SEE "REVISED").
13. **REVISED.** Applied when stratigraphic rank, contacts (new name applied to rocks below or above), affiliations (divided into units of lesser rank; assigned to a unit of higher rank), or spelling of name has been changed. (ALSO SEE "REDESCRIBED OR REDEFINED")
14. **REINSTATED.** Reserved for reinstatement of abandoned names in accordance with the NACSN 1983 Code. Original definition may be accepted or modified in report. Please include reasons for reinstatement.

*Adapted from Mac Lachlan, M.E., and others, compilers, 1996, Stratigraphic nomenclature databases for the United States, its possessions, and territories: U.S. Geological Survey Digital Data Series, DDS-6, Release 3, and North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bulletin, v. 67, no. 5, p. 841-875.

Development and Public Review of the Draft "Digital Cartographic Standard for Geologic Map Symbolization"

By David R. Soller[1] and Taryn Lindquist[2]

[1]U.S. Geological Survey
908 National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6937
e-mail: drsoller@usgs.gov

[2]U.S. Geological Survey
345 Middlefield Rd, MS 951
Menlo Park, CA 94025
Telephone: (650) 329-5061
Fax: (650) 329-5051
e-mail: tlnquist@usgs.gov

From May 19 through September 15, 2000, the Federal Geographic Data Committee's Geologic Data Subcommittee is conducting a public review of a proposed digital cartographic standard for geologic map symbolization. [The Geologic Data Subcommittee of the Federal Geographic Data Committee (FGDC) is responsible for coordination of geologic data-related activities among Federal agencies. The Subcommittee promotes the collection, use, sharing, and dissemination of geologic map information.] Comments and guidance are welcomed from all interested parties including members of the general public, private companies and consultants, state geological surveys, and other government agencies. After the public review, all comments will be considered and the draft will be revised accordingly. If all comments have been addressed to the FGDC's satisfaction, the revised draft then will be approved as a Federal standard.

WHY DO WE NEED A STANDARD?

This draft standard is intended to provide to the Nation's producers and users of geologic-map information a single, modern standard for the digital cartographic representation of geologic features. The objective in developing this national standard for geologic map symbols, colors, and patterns is to aid in the production of geologic maps and related products, as well as to help provide maps and products that have a consistent appearance.

If approved by the FGDC following the public review period, this draft standard will apply to geologic-map information published by the Federal government in both offset-print and plot-on-demand formats. It also is suitable for use in electronic publications (for example, in a Portable Document Format (PDF) file) and for display by computer monitors. Non-Federal agencies and private companies that produce geologic-map information are urged to adopt this standard as well.

DEVELOPING THE STANDARD

This new draft standard has been developed by members of the USGS Geologic Division's Western Publications Group and National Geologic Map Database (NGMDB) project (Table 1). It draws heavily upon previous work by USGS geologic and cartographic personnel (U.S. Geological Survey, ca. 1975 and 1995), and the standards-development group gratefully acknowledges their contributions. In particular, we acknowledge Mitchell Reynolds (USGS, retired) for leading the preparation of the previous draft (U.S. Geological Survey, 1995).

In 1995, a proposed standard was informally released by the USGS (U.S. Geological Survey, 1995). In 1996,

Table 1. Preparers of This Draft Standard. Unless otherwise noted, each individual contributed to both the Working Draft and the Public Review Draft.

David R. Soller (USGS; Chief, National Geologic Map Database)—Coordinator, FGDC draft standard development.

Taryn A. Lindquist (USGS; Digital Map Specialist, Western Publications Group)—Editor and compiler, FGDC draft standard document; coordinator, PostScript and ArcInfo implementations; designer, line symbols for PostScript and ArcInfo implementations.

Sara Boore (USGS; Publication Graphics Specialist, Western Publications Group)—Designer, FGDC draft standard document, point and line symbols, color charts and patterns for PostScript implementation.

F. Craig Brunstein (USGS; Geologic Map Editor, Central Publications Group)—Technical reviewer, FGDC Working Draft.

Alessandro J. Donatich (USGS; Geologic Map Editor, Central Publications Group)—Technical reviewer, FGDC Working Draft.

Kevin Ghequiere (USGS; Cartographer, Western Publications Group)—Designer, patterns for PostScript implementation.

Richard D. Koch (USGS; Digital Map Specialist, Western Publications Group)—Designer, point symbols for ArcInfo implementation, geologic age symbol font.

Diane E. Lane (USGS; Geologic Map Editor, Central Publications Group)—Technical reviewer, FGDC Working Draft.

Susan E. Mayfield (USGS; Publication Graphics Specialist, Western Publications Group)—Designer, FGDC draft standard document, color charts and patterns for PostScript implementation.

Kathryn Nimz (USGS; Digital Map Specialist, Western Publications Group)—Designer, patterns for PostScript and ArcInfo implementations.

Glenn Schumacher (USGS; Publication Graphics Specialist, Western Publications Group)—Designer, bar scales, mean declination arrows, and quadrangle location maps.

Stephen L. Scott (USGS; Publication Graphics Specialist, Western Publications Group)—Designer, FGDC draft standard document, point symbols and line symbols for PostScript implementation.

Will Stettner (USGS; Cartographer, Eastern Publications Group)—Technical reviewer, FGDC Working Draft.

José F. Vigil (USGS; Motion Graphics Specialist, Western Publications Group)—Designer, geologic age symbol font.

Jan L. Zigler (USGS; Geologic Map Editor, Western Publications Group)—Technical reviewer, FGDC Working Draft.

this proposed standard was formally reviewed by geologists and cartographers in the USGS, the Association of American State Geologists (AASG), which represents the state geological surveys, and the FGDC's Geologic Data Subcommittee (GDS), which is composed mostly of representatives from Federal agencies that produce or use geologic map information. That review (Soller, 1996) indicated the need for some revision to the proposed standard prior to its consideration by the FGDC for adoption as a Federal standard.

In 1996, plans were outlined to create a revised and updated Federal standard, and the standards-development group was formed. A proposal to develop the revised standard was submitted by the FGDC's GDS (see <http://ncgmp.usgs.gov/fgdc_gds/mapsymbprop.html>), and the FGDC accepted that proposal in 1997. Later that year, the standards-development group produced a preliminary, beta version of the draft standard, which was circulated among selected USGS and state geological survey personnel for review. Comments were incorporated and, in 1999, the revised draft standard (Working Draft) was submitted to the FGDC's GDS for consideration. Upon review and subsequent approval by the GDS, the Working Draft was submitted to the FGDC Standards Working Group, which approved the document for public review, pending adoption of minor changes. The changes were made, and this new draft standard document (Public Review Draft) became available to the public for review and comment on May 19, 2000. The public review period will extend through September 15, 2000.

WHAT HAPPENS AFTER THE PUBLIC REVIEW?

Upon completion of the 120–day public review period, comments to the Public Review Draft will be considered, and any necessary revisions will be made. The revised draft standard document then will be submitted to the FGDC for formal approval as the Federal standard for geologic map symbolization.

After the standard is formally approved by the FGDC, the intention is that it will become a "living" standard — that is, it will be maintained and revised as needed to reflect new mapping disciplines or evolving usage conventions. The initial release of the FGDC–approved standard document will be available in printed form and supplemented by an electronic (PDF) version. Thereafter, updates to the standard document will be reflected in an online version, which will become the authoritative reference.

To help users maintain an up-to-date hard-copy version of the standard document, the initial release will be printed in "loose-leaf" format. Subsequent updates to the standard document will be made available in PDF format only, which could then be printed on a local output device and inserted where appropriate into a loose-leaf binder.

WHAT'S IN THE STANDARD?

In this new draft standard, descriptions, examples, cartographic specifications, and notes on usage are provided for a wide variety of symbols (see for example, figure 1) that may be used on typical digital geologic maps or related products such as cross sections. In the preparation of this standard, every effort was made to retain the original symbols and their specifications from the 1995 USGS proposed standard (U.S. Geological Survey, 1995); however, many updates have been incorporated into this new version. The number of symbols has increased significantly, from about 800 to almost 1200. Symbols are more logically grouped; some sections have been combined with others, and a few new sections have been added. A newly revised chart that shows a wide range of CMYK colors has been included. An offset-print version of this chart has been in use at the USGS for many years, and the variety of colors has proved to be sufficient for portraying complex geology shown on most maps, regardless of the output medium. In addition, a chart that shows commonly used geologic patterns has been added. The patterns themselves are similar to what was in the 1995 USGS proposed standard, but most have undergone lineweight changes to facilitate digital output at high resolutions. Table 2 lists the contents of the standard.

HOW CAN I GET THE STANDARD?

The draft standard is available at the GDS web site <http://ncgmp.usgs.gov/fgdc_gds/mapsymb>, in PDF format. A paper copy also may be obtained upon request; ordering instructions are found at the web site.

Because this new standard is intended for use with digital applications, an electronic implementation of the Public Review Draft has been prepared in PostScript format, and it is informally released as a USGS Open-File Report (U.S. Geological Survey, 1999, <http://geopubs.wr.usgs.gov/open-file/of99-430/>). This PostScript implementation will enable reviewers to directly apply the standard to geologic maps or illustrations prepared in desktop illustration and (or) publishing software. As the formally approved standard evolves, the PostScript implementation will be updated as well. Additionally, partial work on an ArcInfo (v. 7x) implementation has been completed, and this implementation may also be informally released as a USGS Open-File Report in the future. Information regarding updates to these and other implementation efforts will be posted on FGDC's GDS website, <http://ncgmp.usgs.gov/fgdc_gds>.

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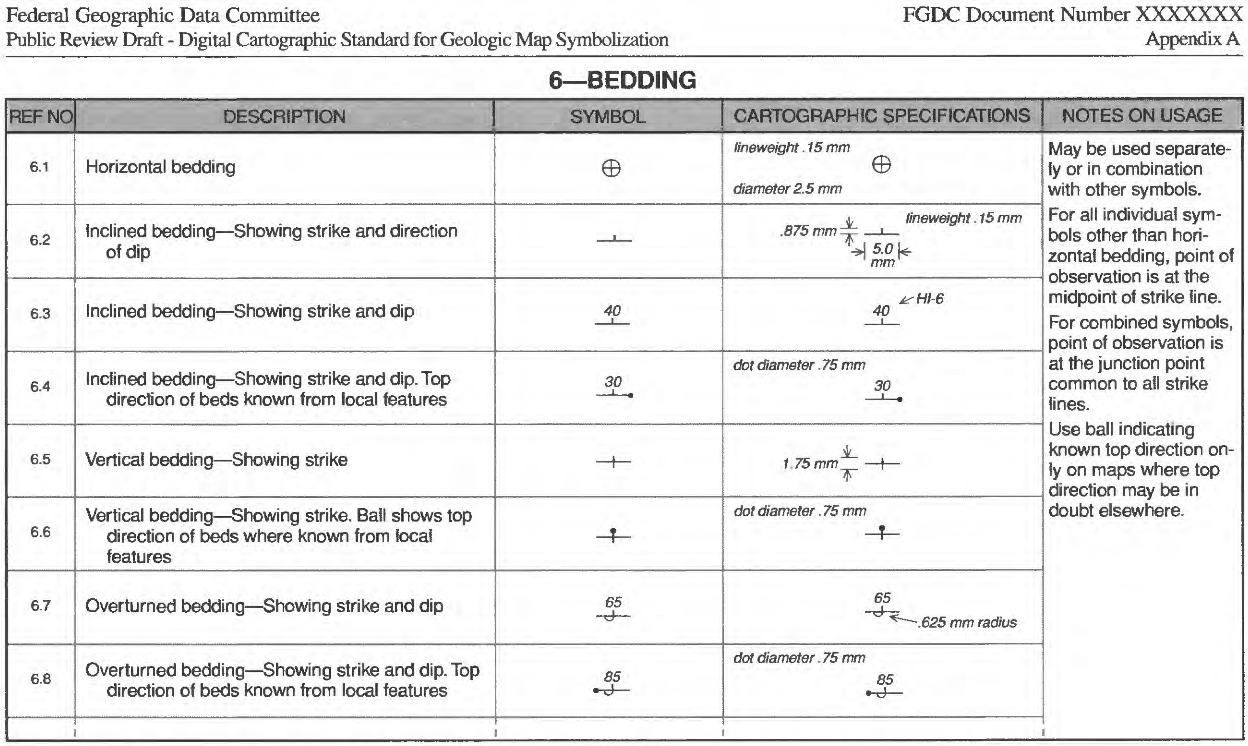

Federal Geographic Data Committee — FGDC Document Number XXXXXXX

Public Review Draft - Digital Cartographic Standard for Geologic Map Symbolization — Appendix A

6—BEDDING

REF NO	DESCRIPTION	SYMBOL	CARTOGRAPHIC SPECIFICATIONS	NOTES ON USAGE
6.1	Horizontal bedding		lineweight .15 mm; diameter 2.5 mm	May be used separately or in combination with other symbols. For all individual symbols other than horizontal bedding, point of observation is at the midpoint of strike line. For combined symbols, point of observation is at the junction point common to all strike lines. Use ball indicating known top direction only on maps where top direction may be in doubt elsewhere.
6.2	Inclined bedding—Showing strike and direction of dip		.875 mm; lineweight .15 mm; 5.0 mm	
6.3	Inclined bedding—Showing strike and dip	40	40 HI-6	
6.4	Inclined bedding—Showing strike and dip. Top direction of beds known from local features	30	dot diameter .75 mm; 30	
6.5	Vertical bedding—Showing strike		1.75 mm	
6.6	Vertical bedding—Showing strike. Ball shows top direction of beds where known from local features		dot diameter .75 mm	
6.7	Overturned bedding—Showing strike and dip	65	65; .625 mm radius	
6.8	Overturned bedding—Showing strike and dip. Top direction of beds known from local features	85	dot diameter .75 mm; 85	

Figure 1. Example of the standard, from "Section 6 — Bedding."

Table 2. Contents of the Standard.

1. Contacts, Key Beds, and Dikes
    - 1.1 Contacts
    - 1.2 Key Beds
    - 1.3 Dikes
2. Faults
    - 2.1 Faults (Vertical, Subvertical, Reverse, or Unspecified Offset or Orientation); Shear Zones; Minor Faults
    - 2.2 Normal Faults
    - 2.3 Strike-Slip Faults
    - 2.4 Thrust Faults
    - 2.5 Overturned Thrust Faults
    - 2.6 Detachment Faults
3. Boundaries Located by Geophysical Surveys
    - 3.1 Boundaries and Faults Located by Geophysical Methods
    - 3.2 Geophysical Survey Lines and Stations
4. Lineaments and Joints
5. Folds
    - 5.1 Anticlines; Antiforms
    - 5.2 Asymmetric, Overturned, and Inverted Anticlines
    - 5.3 Synclines; Synforms
    - 5.4 Asymmetric, Overturned, and Inverted Synclines
    - 5.5 Monoclines
    - 5.6 Minor Folds; Boudinage
    - 5.7 Free-Form Fold Symbology
6. Bedding
7. Cleavage

8. Foliation
    8.1 Foliation and Layering in Igneous Rock
    8.2 Foliation and Layering in Metamorphic Rock
9. Lineation
10. Paleontological Features
    10.1 Fossil Localities; Biostratigraphic Zone Boundary
    10.2 Fossil Symbols
11. Isopleths
    11.1 Lines of Equal Physical or Chemical Properties
    11.2 Geophysical and Structure Contours
12. Fluvial and Alluvial Features
13. Glacial and Glaciofluvial Features
14. Periglacial Features
15. Lacustrine and Marine Features
16. Eolian Features
17. Landslide and Mass-Wasting Features
18. Volcanic Features
19. Natural Resources
    19.1 Veins and Mineralized Areas; Metamorphic Facies Boundary; Mineral Resource Areas
    19.2 Areas of Extensively Disturbed Ground and Workings as Mapped Units
    19.3 Mining and Mineral-Exploration Symbology
    19.4 Mines and Underground Workings
    19.5 Oil and Gas Fields; Wells Drilled for Hydrocarbon Exploration or Exploitation
20. Hazardous Waste Sites
21. Neotectonic and Earthquake-Hazard Features
22. Plate-Tectonic Features
23. Miscellaneous Uplift and Collapse Features
24. Terrestrial Impact-Crater Features
25. Planetary Geology Features
26. Hydrologic Features
    26.1 Hydrography and Hydrologic Feature Identification Symbology
    26.2 Water Wells
    26.3 Water Gaging Stations
    26.4 Quality-of-Water Sites
    26.5 Springs
    26.6 Miscellaneous Hydrologic Symbols
27. Weather Stations
28. Transportation Features
29. Boundaries
30. Topographic Features
31. Miscellaneous Map Elements
32. Pattern Chart (Plate B)
33. Suggested Stratigraphic-Age and Volcanic Map-Unit Colors
    33.1 Stratigraphic-Age Map-Unit Colors
    33.2 Volcanic Map-Unit Colors
34. CMYK Color Chart (Plate A)
35. Bar Scales
36. Mean Declination Arrows
    36.1 Magnetic North, East of True North
    36.2 Magnetic North, West of True North
37. Quadrangle Location Maps
    37.1 Individual States; District of Columbia; Guam; Puerto Rico; U.S. Virgin Islands
    37.2 Conterminous States
38. Geologic Age Symbol Font ("StratagemAge")

Developing the National Geologic Map Database, Phase 3 — an Online, "Living" Database of Map Information

By David R. Soller[1], Thomas M. Berg[2], and Ron Wahl[3]

[1]U.S. Geological Survey
908 National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6937
e-mail: drsoller@usgs.gov

[2]Ohio Geological Survey
4383 Fountain Square Dr.
Columbus, OH 43224
Telephone: (614) 265-6988
Fax: (614) 268-3669
e-mail: thomas.berg@dnr.state.oh.us

[3]U.S. Geological Survey
Box 25046, Denver Federal Center, MS 913
Denver, Co 80225
Telephone: (303) 236-1320
Fax: (303) 0214
e-mail: rwahl@usgs.gov

The provisions of the Geologic Mapping Act of 1992 and its reauthorizations in 1997 and 1999 (PL106-148) require the U.S. Geological Survey (USGS) to design and build a National Geologic Map Database (NGMDB), with the assistance of the state geological surveys and other entities participating in the National Cooperative Geologic Mapping Program. After discussion among the principal architects of the NGMDB, a general plan for its initial design and evolution was proposed (Soller and Berg, 1995); minor updates to the plan, enhancements, and progress reports have been available yearly since 1997 (Soller and Berg, 1997, 1998, 1999a, 1999b, and this volume).

The NGMDB design identifies three phases to the project; these phases are complementary in nature. Because many maps are not yet in digital form and because many organizations produce and distribute geologic maps, it was decided to first identify and catalog all geoscience maps in the United States, in either paper or digital format. This first phase, a searchable map catalog, is the most fundamental aspect of the NGMDB; it enables users to identify whether a map has been produced for their area and/or theme of interest. The map catalog presently is 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.

Although these activities produce valuable information for the public and the geoscience community, to most of us the "National Geologic Map Database" brings to mind the image of an online database containing geologic map information that can be queried, customized for display, and downloaded. Further, the map information in the database would be a coherent whole composed of the best information compiled from various map sources. The database would be updated as new maps are published and so could be termed a "living" database. Work on the third phase has begun, and is the subject of this paper.

GENERAL CONCEPTS AND REQUIREMENTS

Over the past few decades, significant advances in computer technology now permit complex spatial information to be stored, managed, and analyzed to the satisfaction of a growing number of geoscientists. At the beginning of the NGMDB project, we judged that computer-based mapping was not a sufficiently mature discipline to permit us to develop an online database. Further, technology for display and query of complex spatial information on the Web was in its infancy, and hence was not seriously considered by the NGMDB project as a viable means of delivering useful information to the general public. Now, five years after the project's inception, there exists sufficient digital geologic map data, sufficient convergence on standard data formats, data models, and digital mapping practices, and sufficient technological advances in Internet delivery of spatial information to warrant a research effort aimed at building a prototype, online National Geologic Map Database.

To design an online database, the project has held numerous discussions with geoscientists and the general public, to gauge interest in an online database, and to define its scope. Based on these discussions, it is clear that this database should be:

1) built from edge-matched geologic maps at various scales,
2) managed and accessed as a coherent body of map information, not just as a set of discrete map products,
3) updated by mappers and/or a committee, "on the fly" when new information becomes available,
4) standardized, adhering to a standard data model and with standard scientific terminology, and
5) available to users via Internet browsers and common GIS tools (e.g., ArcExplorer).

Compiling a "Living" Database

The United States is, of course, rarely mapped as a single entity. Instead, the U.S. is covered with a "patchwork quilt" of geologic maps at various scales. These maps range mostly from 1:24,000-scale to more than 1:1,000,000-scale. Of these maps, those of most recent vintage and greatest detail tend to be favored for application to societal issues. However, only at the most regional scale do geologic maps cover any appreciably contiguous area. The challenge in utilizing the existing stock of geologic maps for societal issues lies in the necessary compromise between map "quality" and areal coverage — those maps of highest societal utility tend to be the most modern and detailed maps; for most areas, these maps are unavailable and so older, less detailed maps must be used instead. However, for many scientific uses, such as regional, synoptic studies of large-scale earth science trends and societal issues, more regional mapping is preferred.

Because of these realities, a geologic map database must be comprehensive in its content, providing access to all available geologic maps regardless of scale. These maps should be made available in several forms:

- First, and most basic, each of the published maps that comprise the Database should remain available to the user, in part because it represents a formal, approved document.
- Second, maps of the same scale (e.g., 1:24,000 or 1:100,000) should be available as a coherent body of information. This would entail the integration of all such maps into a single map at each scale.
- Third, maps of all scales should be compiled into a single entity that provides, for each area of the Nation, the best available map information. This integrated map will indeed be a patchwork quilt of information, as the best available map of a given area varies widely in scale and vintage across the Nation.

Both the second and third characteristics of the map database will require a group of scientists and/or a committee to oversee the compilation of this body of information and its attendant metadata. As new maps are published, they must be incorporated into the database. Over time, the map information in the database would change and evolve as new information is added; the database can therefore be described as "living", not static in content.

Implicit in building such a database is the availability of sufficient geologic map information in digital form. Because only a fraction of published maps are now in digital form, the vast collection of published paper maps must be prioritized for conversion to digital form. In the coming years, significant effort will be needed for this conversion activity.

Standards and Guidelines

The compilation of many maps into a coherent whole will be difficult if each source map uses different terminology for describing the stratigraphy and characteristics of the geologic units. If each map was organized differently in digital form, rather than using a standard data model, the integration of data into a coherent whole will be further complicated. The NGMDB project has, for several years therefore, been engaged in helping to develop a set of standards and guidelines for digital geologic maps. Information on these standards- and guidelines-development activities can be found elsewhere in this volume and at the project website, <http://ncgmp.usgs.gov/ngmdbproject>. Within the past year, these standards and guidelines became sufficiently mature to justify research and development of a prototype national database, as described below.

Public Access to the Database

The National Geologic Mapping Act and its reauthorizations (see the Act at <http://ncgmp.usgs.gov>) stipulates that the NGMDB will be developed as a resource for application to societal issues. Public access to, and use of, the online map database is therefore a high priority. Emerging technology for Web-based information delivery offers the significant promise of exposing ever-greater numbers of people to databases such as the NGMDB, with the expectation that they will use the geologic information to address societal and personal issues. However, most Internet users, and the general public, are provided with overwhelming amounts of information, and face the attendant challenges of learning the new tools, methods, and thought processes needed to access and use that information. In short, people are confronted with a bewildering array of daily choices and challenges. As a result, there is an understandable reluctance to learn new ways to access information.

The public will be most likely to use an information delivery system that does not require new software or plug-ins, significant bandwidth, or training. With this in mind, we intend for public access to the NGMDB to occur via commonly-used tools (e.g., web browsers) that do not require extra plug-ins or training to use. In the short term, however, as the prototype database is under development, our emphasis will be develop the "back-end" of the database, the data-management system and the collection of standardized geologic map information. When the system approaches sufficient maturity for the public to use, the project then will design the software interface, or adopt an existing or agency-mandated interface, to allow public access to the online database.

HOW TO BEGIN?

Translating the concepts outlined above into a useful database will require that we:

- develop the necessary standards and guidelines,
- identify, assess, and prioritize for digitization the available (paper) geologic maps,
- convert the prioritized maps to digital form,
- build prototypes to test the concepts, standards, and software, and
- provide forums for public discussion of the prototypes, and for reflection on whether the prototype is "headed in the right direction." Most importantly, is the database, as envisioned in the prototype, something the geoscience community really wants, and will find useful?

These requirements are now being addressed. As noted above, the geoscience community has begun to converge on some accepted standards and guidelines for digital geologic maps. In 1999, we designed some basic requirements for a prototype geologic map database, and tested our concepts usings some newly-developed digital data for the Greater Yellowstone Area (Wyoming and Montana) (Wahl and others, this volume). That first prototype was presented for discussion at the Geological Society of America Annual Meeting, in October, 1999. The prototype was well-received, and plans were begun for a second prototype, with a more complex set of tasks.

Plans for the Second Prototype

Following a series of meetings in late 1999 between the USGS, the Kentucky Geological Survey (KGS), and representatives of various state constituency groups and vendors, the second prototype was designed. In 2000, funds were secured, contracts were written, and the work began in mid-year. This prototype will address a limited number of objectives, because the goal is not to build a fully-functional online NGMDB; rather, the goal is to develop a firm foundation upon which subsequent prototypes are based and which will, eventually, evolve into the online, "living" NGMDB. This prototype's objectives are to:

- implement the standard geologic map data model, in an object-oriented software architecture. The current version of the conceptual data model, v.4.3, is relational (see <http://geology.usgs.gov/dm> for information). An object-oriented architecture was selected in order to explore its potentially greater facility for representing and managing complex spatial information.
- accommodate in the data model the capacity to manage "stacked" geologic units, essentially a three-dimensional model of surficial and subsurface geology.
- manage information derived from many source maps. The KGS is conducting a program to convert to digital form the entire statewide coverage by published,1:24,000-scale geologic maps (Anderson and others, 1999). For this prototype, at least two 1:100,000-scale quadrangles, each containing 32 edge-matched 1:24,000-scale quadrangles, will be loaded into the database.
- use a software system that is designed to manage multiple versions of each object on a map (e.g., the outcrop belt of the "X" Formation as shown on various maps of a region), and a large number of editorial changes to each object as submitted by various authors, compilers, and editors. This

objective is designed to explore how the system manages the various overlapping maps in the database, and how it performs long transaction/version management; this feature will be essential to development of the living database.
- demonstrate links between the prototype map database and related geoscience databases (i.e., the KGS coal database, the USGS geologic names lexicon). Conceptually, the user would select a map unit and, upon request, view the summary of information about the unit's geologic name, which is stored in a separate database.
- develop the capability for users to select an area of the map for downloading to their computer. Investigate delivery of both "on the fly" interactive specification of map area, and pre-processed data for commonly-specified areas (e.g., by county, quadrangle).
- evaluate the interagency, collaborative nature of this effort, especially mechanisms by which agencies can retain ownership of their data when held in a jointly-build database.

When the prototype's objectives are met, we will provide opportunities for discussion and comment, through public meetings.

SIGNIFICANT NON-TECHNICAL CONSIDERATIONS

Through this prototype and, hopefully, its successors, the agencies collaborating on the NGMDB will have the opportunity to evaluate the various approaches to serving their map data, both independently and through the NGMDB. In fact, this prototyping process is not just concerned with a set of technical issues — a significant outcome will be a clearer understanding of the opportunities and challenges in collaboratively building a database whose ownership and infrastructure is shared by numerous agencies. This complex issue will receive careful attention throughout the prototypes, which are designed to explore the nature of the relationship among the NGMDB collaborators.

Finally, we draw attention to another significant, nontechnical, aspect of the prototypes — if the concepts here outlined are to be adopted, and a national database created, the system by which scientists are rewarded and promoted will require significant change. Scientists at the geological surveys are evaluated for promotion, and rightly so, by measures of their significant contributions to the science and to society. Historically, the principal measure is the publication record. Development of a national database will require significant scientific contributions from many scientists, but each contribution likely would not generate a discrete publication attributable to a scientist. Rather, the result would be an improved national database of geologic map information to which a scientist contributed. That contribution may be a significantly redefined stratigraphy or set of geologic contacts for an area, but how would that contribution be evaluated? Clearly, agencies will need to evaluate scientists based on an expanded set of criteria that would include contributions to the body of information and knowledge maintained in a "living" database.

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Developing the North American Geologic Map Data Model

By the North American Data Model Steering Committee

Members:
Dave Soller (Committee Coordinator and U.S. Geological Survey, drsoller@usgs.gov)
Tom Berg (Ohio Geological Survey, thomas.berg@dnr.state.oh.us)
Boyan Brodaric (Geological Survey of Canada, brodaric@gsc.nrcan.gc.ca)
Jim Cobb (Kentucky Geological Survey, cobb@fido.mm.uky.edu)
Bruce Johnson (U.S. Geological Survey, bjohnson@usgs.gov)
Murray Journeay (Geological Survey of Canada, MJournea@nrcan.gc.ca)
Rob Krumm (Illinois State Geological Survey, krumm@zydeco.isgs.uiuc.edu)
Jon Matti (U.S. Geological Survey, jmatti@usgs.gov)
Scott McColloch (West Virginia Geological and Economic Survey, mccolloch@geosrv.wvnet.edu)
Peter Schweitzer (U.S. Geological Survey, pschweitzer@usgs.gov)
Loudon Stanford (Idaho Geological Survey, stanford@uidaho.edu)

The development of a standard data model for geologic map information will benefit the geoscience community by providing the common structure for describing geologic phenomenon and for managing the spatial and attribute information in publicly-accessible computer systems. In North America, representatives of geological surveys in Canada and the United States have agreed to work together to address the challenges of building a standard data model and the software tools that permit it to be effectively used. They are working together through the mechanism of the North American Data Model Steering Committee (NADMSC).

Evolution of this cooperatively-developed data model is documented in various informal papers from 1996 to present (for example, Geologic Map Data Model Steering Committee,1999). The data model described in those papers is conceptual in nature, because this work was necessary before the concepts could be evaluated and implemented in various computer systems. Attention is now turning toward testing and implementation; several papers in this Proceedings volume describe efforts to begin to implement the concepts, and more certainly will follow in the years ahead. Because the conceptual model could not stipulate the nature of the GIS and database software in which an agency might choose to develop a geologic map database, there likely will be modifications to the conceptual model as it is test-implemented in various systems across the U.S. and Canada. This is to be expected, as the data model evolves from a conceptual to a physical state.

The geoscience community is composed of diverse agencies and individuals, with a wide range of technical expertise, budgets, and user-support requirements. Therefore, the NADMSC expects that when the various Canadian and U.S. geological surveys evaluate and implement the data model in the coming years, they will modify it as needed to suit their system and user requirements. The role of the NADMSC will be to support these implementations with: 1) technical assistance and data model documentation; 2) modifications to the conceptual model as needed; 3) coordination of software tool development; and 4) the proposal of standard scientific terminology with which to attribute digital geologic maps. To fulfill these roles, the NADMSC has formed six Technical Teams, as follows:

- 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, deliberations of the other technical teams, and user comments);
- Scientific Language (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).

Each Technical Team is now staffed and is conducting its assignment. Within one year, measureable progress is expected and will be reported at the NADMSC Web site, <http://geology.usgs.gov/dm/>, and in public venues such as these Proceedings. Interested persons are invited to register at the site and, through comments, guidance, and test-implementations, contribute to the data model's continued evolution.

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Application of a Digital Geologic Map Data Model in ArcView GIS

By Loudon R. Stanford and Vance T. MacKubbin

Idaho Geological Survey
3rd Floor Morrill Hall
University of Idaho
Moscow, ID 83844-3014
Telephone: (208) 885-7479
Fax: (208) 885-5826
e-mail: stanford@uidaho.edu

INTRODUCTION AND HISTORY

The Idaho Geological Survey has been producing geologic maps digitally since 1989. The Idaho Survey began to capture a database of basic geologic attributes associated with each geologic feature on a map in 1992 as part of its map digitizing process. Beginning in 1996, metadata, or information about the map and its sources, has been input for each 30 x 60 minute geologic map compilation. The attributed spatial data can be used in a Geographic Information System (GIS) to perform simple queries or analyses. However, to receive consistent and meaningful answers to complicated questions about the geology on a digital map requires yet another database of map information, derived from the map legend.

Taken together, the spatial map data, map legend, and metadata comprise a digital geologic map database. The design of these data sets and how they ***relate*** to one another to supply reasonable interpretations of the map is a ***digital geologic map data model*** (Tsichritzis and Lochovshy, 1982).

Currently, many groups are working on geologic map data model design. One of the best known of these to date is the U.S. Geological Survey (USGS), Geological Survey of Canada (GSC), and Association of American State Geologists (AASG) effort: *Digital Geologic Map Data Model Version 4.3a* (Johnson and others, 1999). For a review of the various geologic map data model efforts see Richard (1999). Currently the North American digital geologic map data model Steering Committee (NADMSC) is forming technical working groups to tackle many of the thorny issues involved in developing a North American Data Model (NADM) for geologic mapping.

The tables that hold map information and which make up the geologic map database are the heart of the model. These tables can be manipulated, related, or translated. One of the goals set by the NADMSC is to develop translating tools which will enable different "flavors" of the data model to be migrated to one central format for exchange and archiving purposes. There is at present no data model standard or implementation protocol.

IMPLEMENTING A GEOLOGIC MAP DATA MODEL

Data Users

Demand for better geologic map data has traditionally come from within the geologic profession. But with the advent of GIS technology, new customers are requesting digital geology data sets to aid in analysis of problems as varied as the relationship of geology to tree nutrition or fresh water fisheries. To meet this need for better and smarter digital geology, the Idaho Survey began work on a data model design and implementation that would be "user friendly" and that could be understood by a non-geologist as well as a geologist.

Which Maps to Apply the Data Model To?

The Idaho Survey is a small agency with limited resources. The benefits of developing and implementing a geologic map data model must be weighed against the costs. The Idaho Survey already has a well established set of procedures for capturing and publishing geologic maps. Implementation of a data model at the Idaho Survey by necessity needed to be developed as an extension to existing procedures and software protocols.

The Idaho Survey has historically produced geologic map compilations in paper format, providing the map customer with a synopsis of the current, best geology for a given area. They also provide an economical format: covering the most geology for the least money. For several years the Survey has been committed to digitally compiling 30 x 60 minute maps. These compilations are constructed using a combination of existing geology and new mapping and are the only maps to which we are presently applying the data model. Geologic map sources for the 30 x 60 minute quadrangles are digitized from source materials at original scale where possible. Each map object receives a source identifier code. In this way, simple queries can determine map sources, and source map metadata, within the compiled geologic map. Several advantages are gained by using 30 x 60 minute compiled geologic map tiles, as the backbone of digital geologic mapping at the Idaho Survey:

- Map format fulfills most of our customer's data needs
- Map data can be designed for merging with adjoining maps
- Maps can be edge matched
- Most geology for the money
- Idaho Survey procedures already in place can be used (limited re-tooling)

Data Model Design and Additions

The Idaho Survey relied heavily on the USGS/AASG proposed model 4.3a (Johnson and others, 1999) for the design of its data model. Because of our plan to limit the data model to 30 x 60 minute compilations, and because of additional needs, we added some data elements to this structure:

- History table–tracks original source map units
- Lithology modifier tables–texture, minerals, structures
- Map unit modifier tables–genetic/environment origin tables and form/landform tables

More information, including a complete table flow chart, can be found at the Idaho Survey web site <www.idahogeology.org>. Look for links to the *Digital Geologic Mapping lab (DMG)* first, and then the *Data Model.*

Tool Development Environment and Software Platform

Without software query tools to access and retrieve the information held in the geologic map database, only users with considerable expertise in database manipulation and GIS could work with our data. Even for experts, map data queries would be slow and cumbersome. Good query tools open up the power of the data model to a much larger group of data users.

For many reasons, the Idaho Survey chose to develop the query tools around ArcView GIS. ArcView provides a widely used, relatively easy working environment with a good programing language (Avenue) which allows easy development and data set distribution.

Major Features of the Idaho Survey Data Model

There are currently three major functions which the Idaho Survey data model tools handle:

- Tools for performing complex, nested queries, and the export of derivative maps and data (ArcView shape files)
- Map browsing tools, similar to the identify button in ArcView
- Merging tools (spatial join) to merge two or more map compilations (tiles)

Remaining Work

Most of the crucial design decisions have been made for the Idaho Survey geologic map data model and preliminarily implemented. What remains to be done is the polishing of the basic software tools and finalizing and incorporating the non-implemented tables into the Idaho Survey model. Testing of the model in ArcView will begin with in-house geologists and will certainly result in the fine-tuning of elements of the data model and its tools. With the design nearly stable, new tools need to be created that will enable a geologist to enter map legend information.

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Prototype Implementation of the NADMSC Draft Standard Data Model, Greater Yellowstone Area

By Ronald R. Wahl[1], David R. Soller[2], and Steven Yeldell[3]

[1]U.S. Geological Survey
Box 25046, Denver Federal Center, MS 913
Denver, Co 80225
Telephone: (303) 236-1320
Fax: (303) 0214
e-mail: rwahl@usgs.gov

[2]U.S. Geological Survey
908 National Center
Reston, VA 20192
Telephone: (703) 648-6907
Fax: (703) 648-6937
e-mail: drsoller@usgs.gov

[3]Technigraphics Systems, Inc.
Fort Collins, CO
Telephone: (970) 224-4996

ABSTRACT

Work by the National Geologic Map Database Project shows that object-oriented modeling implemented in an object-relational software system has the set of characteristics that may best support a useable national geologic map database. The North American Data Model Steering Committee's draft standard data model, with some modification, would be easy to implement in this technology. In addition, the studied object-relational technology has built-in version control, input data verification, and allows for many people to access the database for data retrieval and edit/update functions better than other investigated technologies. This technology has been tested in a proof-of-concept database for the Greater Yellowstone Area, Idaho, Montana and Wyoming.

INTRODUCTION

The National Geologic Map Database Project (NGMDB) is conducted by the U.S. Geological Survey (USGS), in cooperation with the Association of American State Geologists (AASG). A more complete description of the entire geologic map database process is in Soller and Berg (this volume).

The charge by the Congress to the USGS is expressed in the following quote from the Geologic Mapping Act of 1992 and its reauthorizations: "The purpose of ...[this Act]... is to expedite the production of a geologic-map data base for the Nation, to be located within the United States Geological Survey, which can be applied to land-use management, assessment, and utilization, conservation of natural resources, groundwater management, and environmental protection...The Survey shall establish a national geologic-map data base. Such data base shall be a national archive that includes all maps developed pursuant to sections of this Act, the data bases developed pursuant to the investigations under [the appropriate] sections [of U.S. law]..., and other maps and data as the Survey deems appropriate." The full text of the Geologic Mapping Act of 1997 can be found at <http://ncgmp.usgs.gov/ngmact97.html>.

NATIONAL GEOLOGIC MAP DATABASE

The USGS and AASG, through the NGMDB, responded with a plan that would build the database in three phases. They are:

- Phase 1 — build a searchable map catalog containing limited metadata for all published paper and digital maps,
- Phase 2 — develop a suite of digital geologic map standards, and link from the map catalog to existing geologic map data sets that are built according to the evolving set of standards, and
- Phase 3 – create a standardized, online national digital geologic map database, concentrating efforts at least initially on intermediate-scale (1:100,000) maps and smaller-scale (e.g., 1:1,000,000) maps of national coverage.

The work described in this paper focuses on the 1:100,000-scale geologic map series, because it was originally proposed as the candidate data set for the database when the Geologic Mapping Act was enacted.

A USABLE MAP DATABASE

A national geologic map database must be usable by a broad customer base. Experience with building databases, especially when making them available for use on the web, shows that such databases must allow easy data entry and editing as well as allow for straightforward search and data retrieval. In addition, it should have at the least the following characteristics, including interaction with other geoscience databases, seamlessness, data content and retrieval standards, and availability over the Internet.

Interaction With Other Geoscience Databases

The technology used to implement the geologic map database should allow existing and future geoscience databases to interact easily with it. We recognize that three general classes of such related databases are important. They are standards data, complementary geoscience data, and non-geoscience data. Examples of standards data are geologic symbol standards (now in preparation) and geologic names. Standard symbols accessible through the map database will aid in uniform annotation and decoration particularly for lines and points. Use of the USGS geologic names database, called the Geologic Names Lexicon (GEOLEX, see Stamm and others, this volume), will enable access to formal unit names and type section data for rock units in the map database.

Complementary geoscience databases encompass gravity, aeromagnetic, geochemical, paleontological, and geochronologic databases. These databases can contain information essential to the understanding of the geology of an area. Databases containing topography, hydrography, surficial geology, and soil characteristics provide information about the nature of rock properties, control of the topography and hydrography by geologic structures, and kinds of weathering and erosion, and soil formation that have taken place in a region under study.

The third class of related databases encompasses non-geoscience information. Data about culture, vegetation, habitats and range of large herbivores and predators, and pollution are examples. The geologic map database must supply information in a form easily integrable with these others databases because experience shows close connections between geology and ecological environments, land use problems, water quality and water and land pollution analysis.

Importance of Seamlessness

Three methods of organization of geologic map data into a database suggest themselves from available technology. These methods range from a data server holding data in a directory but with no additional information to show relationships that exist among data sets, through a tiled system with the information that would tie the individual data sets together, to a seamless database with all of the data stored as a coherent whole.

The first two styles of database would store map data as data tiles based normally on geographic coordinates or political boundaries. This arrangement would certainly allow easy retrieval of information by quadrangles or counties. If, however, data were needed for a drainage basin, a national or state forest, or some other irregular area, one would need to retrieve the various map tiles that cover the area of interest and then assemble the data into a coherent whole. From experience, this is a time consuming process.

Putting the data in a seamless database is a better approach. More time and effort would be needed when editing or adding to the database, and data retrievals by, for example, quadrangles may be slower than when the data are stored in quadrangle tiles, but the problems related to data retrieval from irregular areas are mostly eliminated. This storage type would require "edge" matching of the data both for geometry and for non-geometry attributes of the data as they merged into the database. However, seamless data storage would benefit research efforts greatly when geologic map data are needed for a project.

Data That is Current

All users of spatial data need the latest and best data when performing analyses of GIS data sets to aid in fundamental geoscience research and in the resolution of land use problems. However, most GIS data are out of date. People, money and time are usually not available to provide timely and important data updates. This problem affects many categories of GIS data sets. For example, all users of information from topographic map data sets must deal with the fact that most of the data are out of date. The USGS 7.5-minute quadrangle series data may, on the average, be twenty years old. This problem has arisen mostly because of the high costs of, and limited resources available for, topographic map revision (see Moore, this volume).

Geologic data are not as voluminous as topographic data, but updates of geologic maps are currently just as slow. New and updated geologic map data must be added easily into the map database in a way that will eliminate some of the delays that normally occur when publishing new geologic map data or amending prior map data. Printing maps on demand by clipping the data on the fly and then using standard map collar information and organization should allow more effort to be put into updating the map database.

However, old geologic map data should not just be discarded or ignored. Historic geologic interpretations, and especially those that record geologic conditions prior to changes such as landslides, riverbed changes, floods, and volcanic eruptions, are invaluable to retain while conducting modern geoscience investigations (e.g., Chirico and Epstein, 2000). In addition, adding, updating, and in general revising geologic map data would be easier and more accurate with earlier data available in the map database while the revision process proceeds.

Use of a Geologic Map Data Model Standard

Geologic map data must be available in a standard set of formats with a standard minimal attribute list and organization. The use of a data model standard would eliminate most of the problems related to data attribute content, especially where standardized lists can simplify analysis of these data, and would remove most problems of attribute names. The lack of these standards is a great hindrance to integrating currently released digital geologic data sets.

Web-Access From a Browser

For a database to be useful to the public, it should have at least three provisions. First, a potential user of the database should require minimal applications software to interact with the data. This means that few, if any "plug-ins", for web browsers would be needed. The user should be able to query the database for basic information about a particular feature simply by pointing to it.

Second, the user should be able to view the data with a number of automatic features that could be disabled as needed. Two kinds of views that are of immediate interest are scale-dependent generalization of the current view of the database, and selection of a viewing area by arbitrary geospatial coordinates, political boundaries (e.g., by county), or ecological boundaries (e.g., by drainage basin). Custom views would be quite useful, especially those generated from digitized boundaries created either interactively on screen or offline and sent to the database interface from a standard file format.

Finally, a data user should have the capability to retrieve data clipped by the area they specified — the data attributes would be stored in a standard data model and the data delivered in a format such as "shape" files. This step is key in completing a transaction with a data user.

A GEOLOGIC MAP DATA MODEL STANDARD

A data model for a database consists of two parts that resemble the description of a language: a vocabulary which includes word lists and types of words in the list (i.e., a data dictionary), and a grammar (i.e., the set of relationships among the components of the data dictionary). A standard data model for geologic map data would then be an agreed-upon vocabulary and grammar that would place the map data into a form that would require essentially no translation to become useful to the user community. The data model needs to be robust, that is, it must have within it the capability to handle every possible type of geologic information, or better and more practical, it must allow extensions to the model that will in no way compromise the basic model.

The USGS, the AASG, and the Geological Survey of Canada have been working on a data model standard formally since 1996 (Raines and others, 1997). The North American Data Model Steering Committee (NADMSC) current data model results from this cooperation. The present version is 4.3 and is available for review and comment at <http://geology.usgs.gov/dm>.

Uses of a Geologic Map Data Model

Currently, geologic map data occur in many forms, and the data content, organization, and file format differ in significant ways. A data model standard will aid the process of data exchange and integration, and analysis. The use of a data model standard for the attribution of geologic map features offers a number of advantages. They include:

- Map Creation will be more efficient if a core set of attribute data is collected for each map regardless of the intended use or purpose of the original map. Standard ways for representing spatial information need to be developed and used for all maps to smooth the progress of retrieval, integration, and analysis.
- Compilation of regional maps from detailed map data will be far less time-consuming if source data are con-

tained in a standard data model, thereby organizing the map data for more efficient manipulation and analysis. Then, the compiler could concentrate on the geologic questions that arise from the change in map scale and the generalization.

- Map publication will be more efficient because those responsible for the publication process would receive data in only one format.
- Geologic map data could be exchanged easily among different organizations because the recipients of such data will know in advance the form of the data content. Spatial analysis of geologic data will be easier because the analyst need not be concerned about various incompatible data attribution and formats.
- With a sufficiently robust data model, generalization and reclassification of geologic data would be much simpler because the analyst will have no need to build data structures to perform these functions.
- Integration of disparate data sets from different disciplines requires a data model standard that is robust and easy to use.

Types of Data Models

The current NADMSC data model deals with data attribution only and places the spatial data into a few boxes in the model. This data model is designed as a relational database model, because the concepts and the terminology of relational database technology are well developed and well understood. Also, such a model is relatively easy to understand and communicate to others.

In contrast, object-oriented modeling is relatively new and holds great promise, but uses rather confusing terminology and suffers from few standard (agreed upon) concepts. Because it is new, object-oriented modeling requires a totally different way to view a digital map and is therefore difficult to accept as either being a valid way to model complex systems or to store data. The Unified Modeling Language (UML) recently has emerged as the apparent standard in which to express the object-oriented approach to analyzing and building new software and data systems. Since users of this technology have yet to agree on object-oriented database concepts and terminology, a hybrid system (an object-relational database design) has been proposed and has found great acceptance with database software systems. This technique allows object modeling to be done in an object-oriented manner and then the actual data to be stored in a relational database. In addition, this technology allows inheritance, encapsulation (with data hiding), polymorphism, and other object-oriented capabilities to be available with the stability of a relational database. See Muller (1999) for a good description of OO terminology as it now appears in most of the literature.

Object-Oriented Data Model for GIS

There are two fundamentally different ways to represent spatial objects in a Geographic Information System (GIS). The most common is a geometry-based system, in which one must choose the geometrical type (polygon, line or point) to represent the object and then attach attributes to the geometry (figure 1a). This kind of system is well known, well defined, and widely used, which gives the user of such a system confidence about the data stored. However, a persistent problem with the geometric-centered system is that users may begin thinking of the spatial objects contained in the system by their geometry types rather that the object they actually are. One may hear geologists referring to geologic map objects in terms of polygons, lines, or points instead of rock outcrops, faults, and strike-and-dip measurements.

In contrast, a better way to represent spatial objects is object-oriented (OO) modeling, which allows the user to think in terms of real world objects. Real-world objects

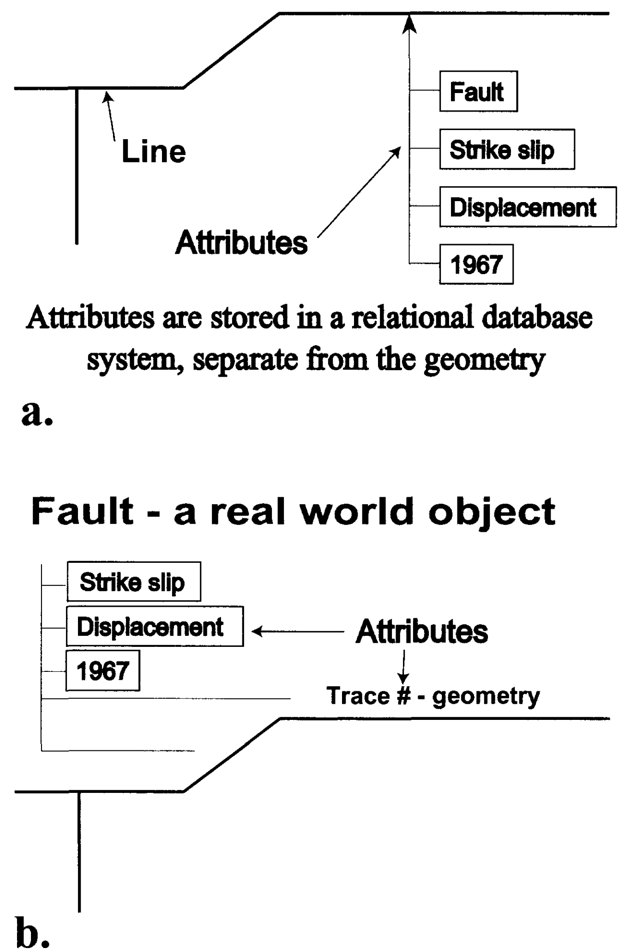

Figure 1. a. Geometry-centered geospatial data system. b. Object-oriented geospatial data system.

such as cars, trees, or, grizzly bears, are described in terms of attributes necessary for the data structure to useful in a particular context. That is, the attribute list for an object in an OO system is not necessarily exhaustive. For an OO GIS, geometry is clearly necessary to represent the object on a map, but it is not the defining attribute for the object. So, on a geologic map stored in an OO GIS an object named "rock outcrop" may use any one of the three planar geometries mentioned above to represent the geometric attribute of an instance of that object.

Object-oriented data models are simpler and easier to build than geometry-centered models. The modeling process is done in terms of real world objects and many of the abstract concepts used in building relational models to support geometry-centered models become irrelevant. Other features are:

- OO models are less dependent on an initial data model for future applications; therefore, the data model can evolve. Generally, changes to the data model do not in most cases mean a total reload of the database.
- In OO models, pieces of program code called methods are "attached" to objects rather than existing in an external program. This makes OO systems more flexible for meeting application needs, and applications are simpler and faster to develop.
- Representations of geologic relationships that involve interactions among geometries and other non-geometric attributes can be built directly into an OO model in terms of methods that describe these relationships as well as attributes. This is possible because geometry is one of the attributes attached to an object in OO GIS systems (figure 1b). Some complex relationships that could be easier to implement in OO models are: the presence of 3-dimensional relations, age relationships modified by other attribute values, and interactions among geometries of a number of objects.

Storage of Geospatial Data

There are two methods used to store completed geospatial data sets. The more common approach stores geometry-centered GIS data as sheets or tiles. This method then uses external software to index and manage the multiple data tiles. With careful design, attribute data for the tiled data sets can be stored in just one database. Mapping by tiles or quadrangles is the traditional way to collect geologic map data principally, because it allows each map product to be linked to the geologist-author (thereby maintaining credit for the work) and because it gives the project organizer an easy-to-manage way of tracking progress. However, any object that is mapped on several maps or quadrangles will be split into as many pieces as there are tiles. For example, geologic data requested for drainage basins, for counties, or for national parks from data stored in a tile-based library must be assembled from the appropriate tiles whenever a user requests a data extraction (figure 2a). A time-consuming evaluation must be made to ensure that the reconstruction of the data has produced an uncorrupted data set.

However, geospatial data including geologic map data are more logically stored in a seamless database using an OO data model. Objects like fault blocks, moraines, and lava flows retain their real-world descriptions when viewed as connected objects, and requests for basic as well as derivative map data within complex boundaries based on objects are therefore easier to retrieve in an OO system (figure 2b).

A GEOLOGIC MAP DATABASE FOR THE GREATER YELLOWSTONE AREA

To test the feasibility of these ideas, the NGMDB performed a proof-of-concept experiment using a mature

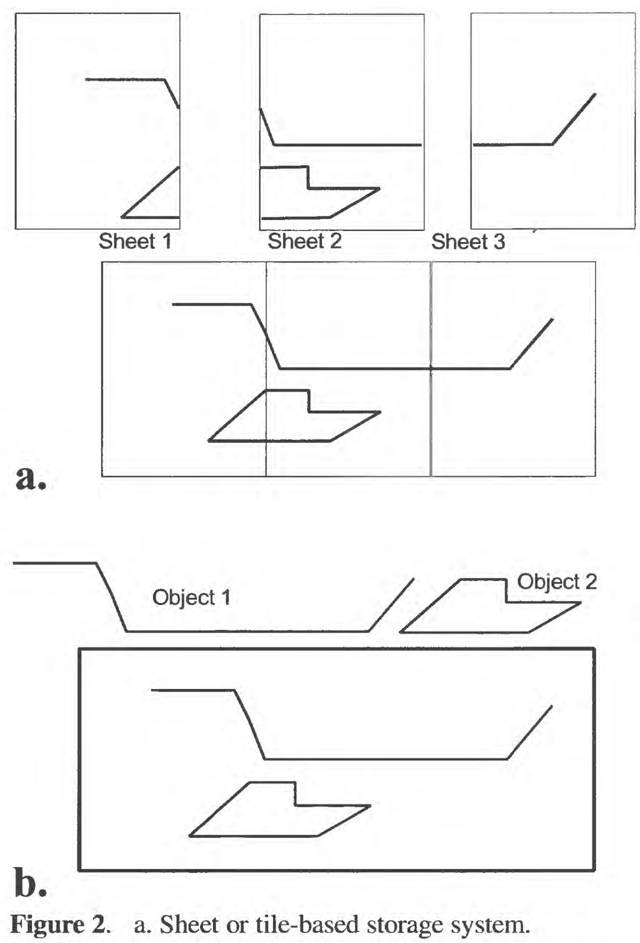

Figure 2. a. Sheet or tile-based storage system. b. Object-oriented storage system.

object-relational GIS software system (Smallworld software) and geologic data from the Greater Yellowstone Area, or GYA (figure 3). This experiment serves two purposes. First, the idea of such a database as pictured above could be tested; and second, the database could supply data for use with other GIS software for the purposes of edit and update, and analysis. A geologic database for the GYA is desirable for a number of reasons:

- Data are needed by the GYA community to investigate man's impact on the landscape, and geology is an essential element.
- Support of the GYA basic science goal to analyze the factors that influence the habitat and the interactions of the major mammal species.
- A comprehensive geologic database is vital to several interdisciplinary studies in the earth and biological sciences in the GYA. Locke, 1998 wrote: "The primary reason for most of the western national parks is geological (and yet)... geological research needs in the parks are almost entirely driven by the curiosity of outside scientists rather than by national needs... We ignore (geologic research there) at our peril." A comprehensive geologic map database is vital to interdisciplinary studies in the geosciences and ecology.

A geologic map database as described above has a number of possible uses including:

- Surficial and groundwater-flow analysis. The regional geologic setting of the GYA affects water volume and water quality outside Yellowstone National Park (YNP). The USGS Water Resources staff is studying these relationships as a part of the National Water Quality Assessment Program (NAWQA).
- Relations between vegetation abundance and diversity, and soil and rock properties. Clear correlations exist between vegetation types and bedrock geology in the GYA. For example, conifer tree types emerging after the 1988 fire in YNP show a definite preference by species to grow on soils from specific volcanic and non-volcanic rock types (Don DeSpain, pers. comm., 1999).
- Soil and rock properties and wildlife presence. One of the tree species that grows on andesite within YNP is white bark pine. Grizzly bears feed on the nuts of that tree for a month (usually September), which implies that if andesite supports white bark pine, grizzlies will be present on the andesite outcrops with white bark pine for that month.
- Analyze subsurface volcanic phenomena. In combination with complementary geophysical data sets, a clear understanding of past volcanic activity in the GYA recorded in the database might offer clues about future volcanic activity there.
- Analyze landslide hazards. In combination with DEMs, slope maps, and vegetation maps, geologic data would help to analyze landslide conditions in the GYA. Historically, landslides have been quite destructive in the GYA.
- Trace minerals in water, plants, and animals. The NGMDB project's work in the GYA has funded analyses of plant and animal samples that show great differences in natural trace element concentrations in various parts of the GYA.

Taken together, the above mentioned uses of geologic data make possible a better understanding of the natural setting of the GYA. For example, building roads and other access and support facilities in places where they would least interfere with the ecosystem and would not exacerbate local geologic hazards would minimize the impact of man on the wilderness.

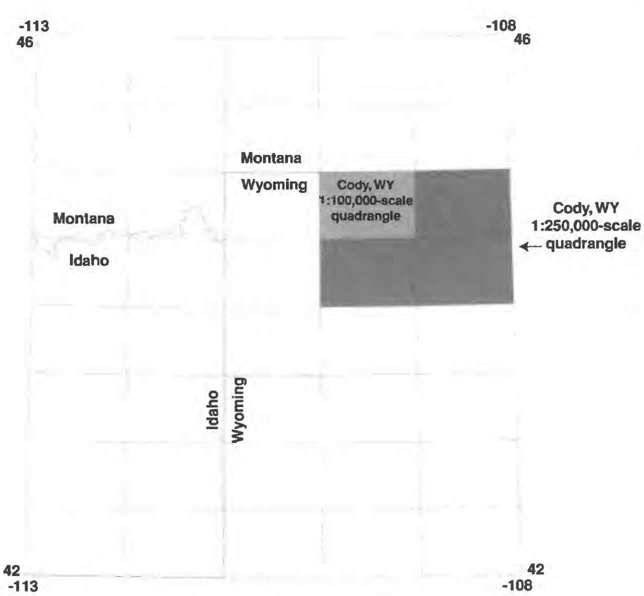

Figure 3. The Greater Yellowstone Area.

Proof of Concept Database

The NGMDB project used a mature object-relational GIS system to make some preliminary tests to answer the following questions:

- Can the NADMSC (v.4.3) data model be implemented in such a system? In our test, it was implemented in a limited fashion, addressing only the attribute tables. Advantages of the OO system were, therefore, not exploited.
- Can such a database be seamless? Yes, it can. In addition, alternative versions or "alternatives" of the data can exist in the database while edits and updates for an area are being done. In fact, these "alternatives" can be used to store prior versions of the geologic interpretation of an area, for comparison with the current version.
- Will such a system allow for easy editing and updates? This functionality was not fully examined in this proof of concept. Editing in this GIS would have a learning curve not unlike ARCEDIT. If a system like this is

used for the national 1:100,000-scale database, most editing for the near term will still be done in currently owned GIS software.

- Can data be extracted and delivered in well-known data formats using version 4.3 of the data model? Delivery in "shape" files with attribute data in "DBF" or other database formats has been done and was relatively easy to implement.
- Is the database web-accessible without custom software or plug-ins to commercial software? The OO map databases implemented in the GIS technology under study are accessible using basic browsers (Internet Explorer or Netscape) without plugins. This approach is in keeping with the OpenGIS Consortium's three-tiered approach to data distribution (figure 4). For more information on the OGC see <http://www.opengis.org>.

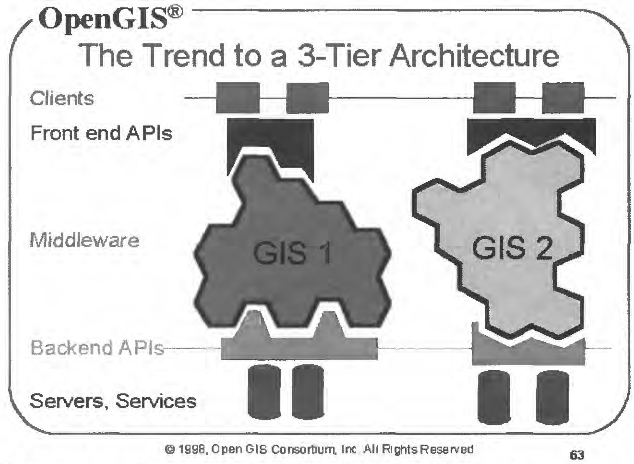

Figure 4. Three-tiered data delivery, with their Applications Programming Interfaces (APIs).

CONCLUSIONS

The proof of concept is a contribution to the experimentation that is necessary for implementing the National Geologic Map Database. Data from the GYA were converted from ArcInfo coverages to "shape" and "DBF" files, and imported into the object-relational software with supplied code. No difficulties were encountered in the process. Preliminary work with third-party translation software shows that direct conversion from ArcInfo coverages to this system would be possible but more testing needs to be done. Use of web browsers as an interface to the online database has passed an initial test. Software zooms into an area, selection of geologic features by pointing with a mouse, and subsequent display of the attributes of the selected feature works well even over a phone line connection.

Work to Be Done

The geologic mapping community needs to find new ways to share digital geologic map data more efficiently with an audience that is broader than our traditional one. Standards are needed for data organization, geologic word lists, and geologic data file content as well as format. More comprehensive interaction with the online database should be designed, to provide for query and Internet delivery of user-selected data in a useable form. In other words, the geologic mapping community needs a standard data model implemented into a "useful" database. More study and discussion are necessary before building such a map database on a national scale.

In addition, the geologic mapping community needs to agree upon a definition of the term "geologic map." Varnes (1974) offered the following definition nearly three decades ago, well before the use geologic map data in digital applications was widely conceived. In particular, his warning about inappropriate uses of geologic map data reminds us of the inherent limits to what one may obtain from a digital geologic map database.

"A geologic map is a synthesis; it is not information in its most fundamental and versatile form. It is a generalization..., a geologist's interpretation of the geology for a particular purpose. Its lines, units, and descriptions may not be sufficiently defined for another synthesis intended for another purpose. If a geologic map does not contains the proper information... it logically cannot, and therefore should not, be interpreted for special purposes; if it does, it can. Facts cannot be generated by inference."

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Geology in the Terrestrial Database of the U.S. Forest Service's Natural Resource Information System (NRIS-Terra)

By Andrew H. Rorick

USDA Forest Service
NRIS-Terra
16400 Champion Way
Sandy, OR 97055
Telephone: (503) 668-1623
Fax: (503) 668-1410
e-mail: arorick@fs.fed.us

INTRODUCTION

The USDA Forest Service is developing a set of corporate, relational databases in which to store, analyze, report on, and display through GIS technology, the data collected by its field-going and research personnel. The Natural Resource Information System (NRIS) includes six Oracle databases: Air, Fauna, Field-Sampled Vegetation, Human Dimensions, Terra, and Water. The NRIS website is located at <http://www.fs.fed.us/emc/nris/>.

The initial release (v. 1.0) of the terrestrial database, Terra, primarily supports the Forest Service's continuing efforts to inventory, and to classify into "terrestrial ecological units," the biophysical landscapes that comprise the national forests. As a consequence, Terra also supports inventory, classification and mapping of the individual resource components of these ecological units: geology, geomorphology, climate, soils, and potential natural vegetation.

Ecological units delimit areas of different biological and physical potentials, the boundaries of which are determined by integrating the resource components listed above (Cleland et al., 1997). Terrestrial ecological-unit inventories (TEUI) are conducted at a variety of spatial scales, and have proved to be an essential tool in understanding ecosystems: to predict how they will react to disturbances and treatments, to define desired conditions, and to plan for ecosystem sustainability.

GEOLOGY IN TERRA

Data Creation and Entry

Both physically and conceptually, the foundation (the bedrock) of TEUI is geology. Geologic data in Terra include lithology, stratigraphy, and structure (figure 1). Lithology includes bedrock and surficial materials, texture, and weathering. Stratigraphy includes lithostratigraphic-, chronostratigraphic-, or tectonostratigraphic-unit names and thickness of surficial cover. Structural data are limited to structure type (i.e., bedding, foliation, fractures, joints); the structure's azimuth and inclination; and dominance, if more than one is being described at any particular location.

Geomorphology (after Haskins et al., 1998) is described by process, landform and morphometry, and would require a separate paper to explain.

The development of Terra also required establishment of corporate data standards and protocols for geology, as well as for the other disciplines. Lithology and rock-texture standards come from Travis's Classification of Rocks (1955), which Forest Service and Bureau of Land Management geologists and mineral examiners have been using for many years. Surficial-materials standards are from NRCS's Glossary of Landform and Geologic Terms (1996). The standard for describing rock weathering is derived from the Unified Rock Classification System of Williamson and Kuhn (1988). Stratigraphic nomenclature comes from sections published by USGS or state geological surveys and from the International Stratigraphic Guide (Salvador, 1994). And the geochronology used in Terra is from the DNAG time scale (GSA, 1983).

The data-entry forms developed for Terra serve to enforce these and other standards by accepting only "valid values" in most of the data fields. Type tables developed to house the data elements listed above are stewarded by one geologist: nationally applied standards (e.g., lithology) are under the care of the national data steward; and there are lower levels of stewardship for regionally applicable standards and for local data standards (e.g., the local stratigraphic column). As one would expect, the process for

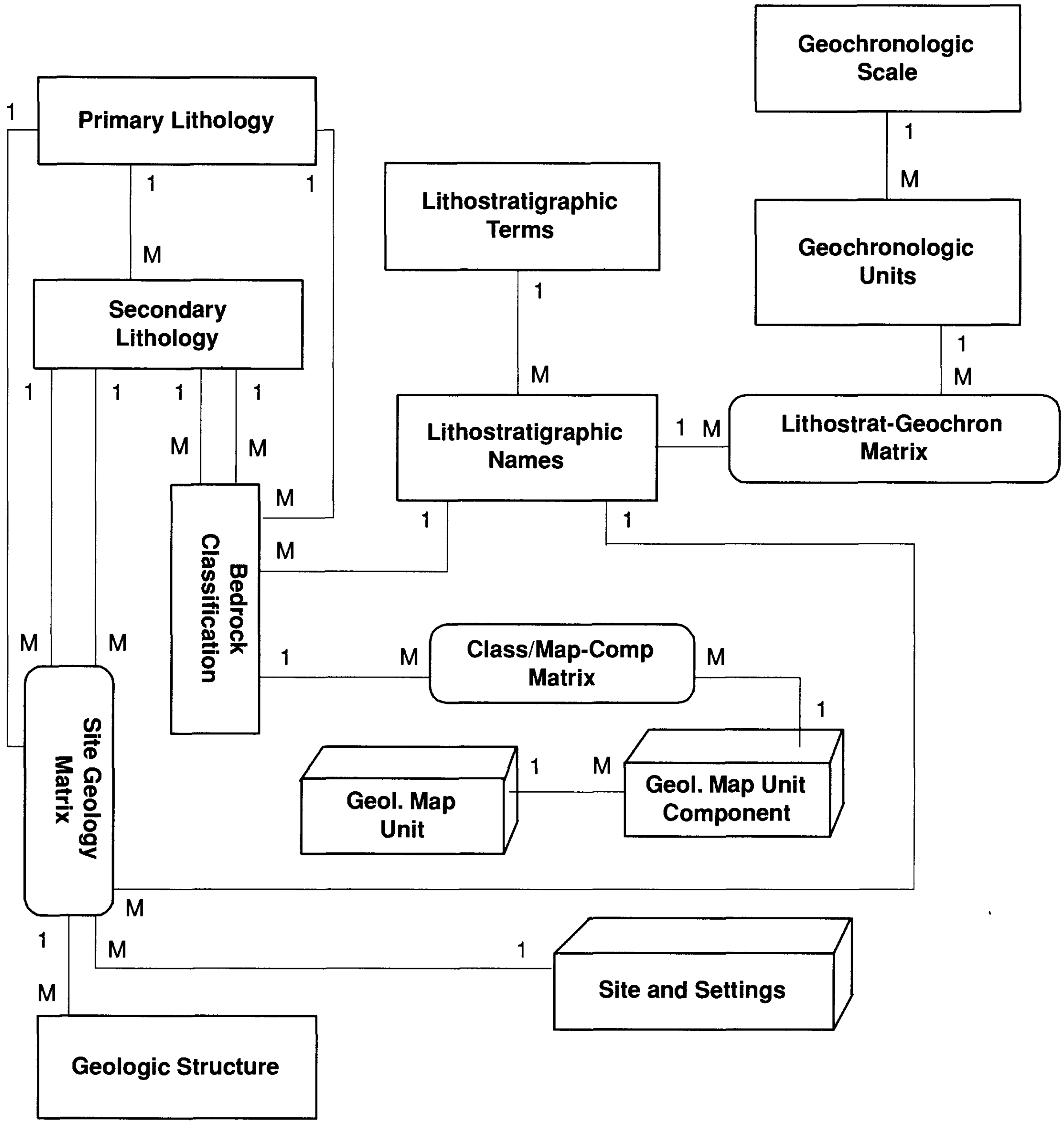

Figure 1. Simplified relational structure diagram for the geology portion of the Terra database. Rectangles represent "maintenance" type-tables that store values appearing in the data-entry form drop-down menus. Three-dimensional objects represent the field-data entry and storage tables. Matrix tables are present to resolve many-to-many relationships.

making changes to the standard type-tables becomes increasingly rigorous as the regional scale of their application increases. These type tables are built through "maintenance" forms in Terra, which must be completed before any field-data entry can begin. Metadata forms also must be filled out before any site or map-unit data can be entered. Terra's metadata include project name, field protocols, methodologies, sample designs, examiners, and references.

The field-data entry for Terra is organized by "site" or "polygon," "classification," and "map unit" (figure 1). Site or polygon data describe unique, physical places on the earth, whereas map units are polygons that may occur in many places across the landscape. Sites or polygons are described using the data entry forms specific to the disciplines collecting the data, e.g., geology. There are also site or polygon "setting" data that include location (public land survey, lat-long, UTM, GPS, etc.) and morphometry (elevation, relief, slope, position, drainage, and dissection). "Line" data (e.g., geologic contacts, fold axes, faults, veins, dikes) are currently supported in Terra, only as linear "polygons," however.

The site/polygon geology forms allow selection from lists of values for rock type, texture, weathering, several modifiers (e.g., silicic, calcareous), fracture interval by class (5 classes from <10 cm to >2 meters), surficial cover and depth by class (4 classes from <2 meters to >6 meters), and stratigraphic unit. The form also allows selection of a structure type (e.g., bedding) and direct entry of strike and dip data. Additional forms are filled out for each different lithology that occurs at the site.

The Map-Unit data entry form contains the map-unit symbol (e.g., Mm) and name (e.g., "Madison Formation"), some general location information, and links to other forms where data are entered to describe the unit more thoroughly. The most important of these is the "Map Unit Components" form. Map units are described by their components, labeled "1," "2," etc.). These, in turn, are described by "classifications." Normally, for geological mapping, each map unit will represent a different stratigraphic unit, and will, therefore, have one component, covering 100% of the map unit, and described by a single-taxon classification (e.g., "Mississippian Madison Limestone"). This classification will be attached to every map unit on the geologic map that contains the Madison. This appears redundant, but it is necessary for Terra to be functional for all disciplines using the database and for integrating the data to determine the ecological map units, to which classifications for soils, geomorphology and potential natural vegetation are also attached.

However, should the mapping scale or litho-stratigraphic uncertainties dictate, more than one component can be assigned to the map unit (e.g., an undifferentiated complex of two components: 60% coming from the classification, "Amsden Formation," and 40% from the classification, "Tensleep Sandstone"). Alternatively, one component, again covering 100% of the map unit, could be created using the two classifications, Amsden and Tensleep.

Geologic classifications may be based on either or both the lithology and stratigraphy of the area being investigated. That is, for Forest Service purposes it is often more important to recognize the lithologic component (micritic limestone) of an ecological map unit, rather than whether the stratigraphy is "Madison" or the time period "Mississippian." Such classifications can be created "on the fly" as map-unit components are being established, and as many as are needed can be attached to a particular component.

Interactivity with GIS

Terra does not create GIS spatial data. The layers or coverages are generated separately, following the agency's draft GIS Core-Data Standards. However, Terra is engineered to provide a link between spatial and tabular data using a software program, "PL/SQL Link to ArcView" (PLA). PLA provides a means to view spatial data interactively with Terra's Oracle Forms so one has a visual representation of the data being entered into or queried from the database. For PLA to work, a series of generic Oracle tables hold spatial/tabular linkage data that identify required source information for both ArcView and Oracle Forms. These tables are loaded as a generic installation in Oracle called the GIS Foundation. Terra then populates these tables with data. Other Forest Service national database applications also use this same GIS Foundation, so a single set of tables will be used as an integration tool for tabular/spatial linkage.

Once the coverages are developed and the PLA is installed, the spatial display of the data in Terra can be triggered from any of the data-entry forms. For instance, while entering or viewing data about the map unit, Madison Limestone, one can click a button and display the geologic map with the Madison units highlighted.

Likewise, by selecting a data point or map unit, or a geographic collection of either, on the ArcView display, the form or series of forms that describes the selected feature or features can be viewed.

Terra also incorporates a set of automated queries, the Terra Extension to ArcView, that spatially displays tabular data from ecological-unit information stored in the database. When the set of data to be displayed, (e.g., lithology or geologic age) is selected from a menu, the data theme or themes are automatically loaded in ArcView and displayed on the map. The extension was developed to display the most common spatial coverages for which Terra stores data, i.e., terrestrial ecological units and the resource components thereof.

In addition, MS Access can be used to develop ad hoc queries from Terra (e.g., select the sites where Madison is the bedrock, colluvium is the surficial material, and liverwort sp. is the dominant vegetation), produce a new table of values, and display them in tabular format, spatially, or both. The data are then available for the various analyses the Forest Service performs.

CONCLUSION

Though Terra was not developed specifically for digital geologic mapping, and lacks adequate support for "line" data, it will serve that purpose until the North American Geologic Map Data Model Steering Committee completes its data model (<http://geology.usgs.gov/dm>). In the meantime, Terra will be undergoing improvements, especially with regard to how geology and geomorphology were modeled for version 1.0. Convergence with the Steering Committee's model is expected because the Forest Service needs the data and coverages that only USGS and the state surveys can provide. Its partnerships with USGS for performing the intricate ecosystems analyses in the Columbia River Basin, the Sierra Nevada, and Greater Yellowstone have demonstrated the absolute necessity of accurate geologic data and coverage.

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The National Park Service Digital Geologic Map Model: Transformation from Paper to Digital, Featuring Legends, Cross Sections, Map Notes and Keyword Searchability

By Steve Fryer[1], Joe Gregson[1], Tim Connors[2], Anne Poole[1] and Bruce Heise[2]

[1]National Park Service
Natural Resources Information Division
1201 Oak Ridge Drive, Suite 350
Fort Collins, CO 80525
Telephone: (970) 225-3584
Fax: (970) 225-3585
e-mail: Steve_Fryer@nps.gov, Joe_Gregson@nps.gov, Anne_Poole@nps.gov

[2]National Park Service Geologic Resources Division
12795 West Alameda Parkway
P.O. Box 25287
Denver, CO 80225
Telephone: (303) 969-2093
Fax: (303) 987-6792
e-mail: Tim_Connors@nps.gov, Bruce_Heise@nps.gov

SUMMARY

Beginning in 1998, the National Park Service initiated a geologic resources inventory (GRI) to document and evaluate the geologic resources of about 265 National Park System units (national parks, monuments, recreational areas, historic sites, seashores, etc.). GRI workshops were held for units in Colorado (1998), Utah and Idaho (1999), and North Carolina (on-going in 2000). New, user-friendly GIS tools have been developed for digital geologic maps of Black Canyon of the Gunnison National Park, Curecanti National Recreation Area, Rocky Mountain National Park, and Craters of the Moon National Monument. Applications, including the NPS-developed ArcView Data Browser, graphical cross section viewer and legend text display tools are integrated with a standard geology-GIS model that is in development. The evolving geology-GIS model is based on the Washington State ArcInfo GIS data model (Harris 1998) that is being adapted for ArcView GIS and extended to include components of the North American Geologic Map Data Model (NADM), <http://geology.usgs.gov/dm/>.

INTRODUCTION

Bedrock and surficial geologic maps and supporting 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 physical science 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 to implement a systematic, comprehensive inventory of the geologic resources in NPS units. Cooperators include the NPS Geologic Resources Division, NPS Inventory and Monitoring (I&M) Program (Natural Resource Information Division), U.S. Geological Survey (USGS), and individual state geological surveys (currently Colorado, Utah, and North Carolina). The GRI for the 265 park units with significant natural resources consists of four main phases:

1.) "GRBib", compilation of a bibliography of geologic literature and maps;

2.) "scoping sessions", an on-site evaluation of park geologic maps, resources, and issues;
3.) digital geologic map products with accompanying supporting information; and
4.) a summary report with basic geologic information on hazards, issues, and existing data and studies.

STATUS OF GEOLOGIC RESOURCES INVENTORIES

The NPS Geologic Resources Division and Inventory and Monitoring Program sponsored a workshop in baseline geologic data in Denver, Colorado in fall 1997 to receive input from the NPS, USGS, state geological survey personnel, and cooperators on needed basic geologic data that Inventory and Monitoring Program could provide. At the meeting, Colorado, Utah, and North Carolina were chosen as pilot project states to maximize cooperation among the agencies and provide consistency in workshop planning. The group discussed and adopted the four main inventory phases that are reviewed briefly below.

Geologic Bibliographies

"GRBib", the bibliography of existing geologic maps and literature for each NPS unit in Colorado, Utah and North Carolina is available on the internet (URL: http://165.83.36.151/biblios/geobib.nsf>; LOGIN: "geobib read", PASSWORD: "anybody") and is also prepared as printable documents at <http://www2.nature.nps.gov/grd/geology/gri/products/geobib/>. Also, geologic index maps showing the location of associated geologic maps and their scale have been prepared for these same parks. In general, after map coverage for each park is determined, map products can be evaluated, and if needed, additional mapping projects identified and initiated.

Park Workshop Meetings

GRI Park Workshops (scoping sessions) were organized in 1998 (Colorado), 1999 (Utah and Idaho), and now in 2000 (North Carolina) to evaluate each park's geologic resources. Park teams have evaluated existing maps for digital products and identified needed geologic mapping. New geologic mapping may be initiated on a case-by-case basis after careful evaluation of needs, costs, potential cooperators, and funding sources.

GRI cooperators are developing geologic-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 paper maps. Pilot digitization projects are providing additional information for the evolving NPS digital map standards.

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.

Upon completion of an inventory in a park, the available geological literature and data from the NPS, USGS, state, and academic institutions will be documented in a summary report. The content, format, and database structure of such reports are still being developed.

Geologic Mapping and Digitizing Projects

The NPS I&M Program has cost-shared new geologic field mapping for Zion NP and Glen Canyon NRA with the Utah Geological Survey. Additional field mapping projects have been initiated or completed for the geologic maps for Bent's Old Fort NHS, Curecanti NRA, Florissant Fossil Beds NM, Great Sand Dunes NM, Capitol Reef NP, Cedar Breaks NM, Golden Spike NHS, and Natural Bridges NM.

Digitization of geologic maps for Arches NP, Black Canyon of the Gunnison NP, Curecanti NRA, Craters of the Moon NM, Rocky Mountain NP, Bent's Old Fort NHS, Natural Bridges NM, and Florissant Fossil Beds NM has been completed.

Preliminary plans are to initiate digitizing projects in 2000 for all Utah parks with completed paper geologic maps (Bryce Canyon NP, Canyonlands NP, Capitol Reef NP, and Timpanogos Cave NM).

The NPS Geologic Resources Inventory is being actively developed with the cooperation of USGS and state geological surveys. However, many opportunities for project collaboration may 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 map unit descriptions, supplemental explanatory text (references and map notes), geologic 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 ESRI (Environmental Systems Research Institute) ArcView GIS. ArcView interfaces effectively with other software running on the Microsoft Windows operating system. Also, using a variety of tools, including the Windows help software, a Microsoft Visual Basic graphics viewer program, the ArcView legend editor, and the Avenue script language, has allowed query and automatic display of published map information in the GIS.

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 Microsoft Windows help file. After testing several options, NPS developers have been implementing the Windows help system.

This approach begins with the creation of the Help file table of contents (object table). The table includes a title, a listing all source map units (sorted by geologic age), and a list of source map references and notes. Text descriptions of map units, paginated by geologic age, are entered next. For compiled geologic maps, maps produced from more than one source map, a unit's description often consists of multiple map unit descriptions. At the end, the source map references and notes text, also one per page, were entered. Help context IDs (HELP_ID), topic names, keywords, page numbers, and linking codes were then added to the footnotes of each page. The data was then saved as a rich text format (.rtf) file, and compiled into a Windows help file.

Once compiled, the Windows help file can be opened and used with almost any Microsoft 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 (GLG_SYM, see data model below) and the corresponding help context ID (HELP_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 interactively 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 Microsoft Visual Basic (VB) graphics viewer program. The cross sections are scanned digital graphics files (JPEG format) 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., "gq1516a.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.

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 (CODESEC, see data model section below) 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.

GIS Map Unit Legend

In ArcView, theme legends can be customized to reproduce map feature symbols and colors of published source maps. To represent map features of a particular theme, an attribute field is selected in that theme's legend editor that relates map feature type with legend symbol type and color. In the NPS geology-GIS data model (presented below), the attribute field that denotes map feature type is typically either COV_TYPE for point themes or COV_LT for line themes, where COV represents the theme/coverage abbreviation. For polygon themes (themes typically representing geologic map units of areal extent), and also for point and line themes that represent point and line geologic map units, respectively, GLG_AGE_NO is the attribute field that relates feature type with symbol type (pattern) and color. As mentioned in the data dictionary section of the paper, the GLG_AGE_NO is a numeric attribute field also used to sort map units by geologic time.

For point symbols that indicate or represent directionality, ArcView also allows for those symbols to be aligned to their correct orientation using a second attribute or rotation field. For attitude observation points, (e.g. strike and dip of bedding, trend and plunge of inclusions ..), which is the only coverage presently in the data model that has oriented point symbols, the ATD_AV_ROT field designates the desired symbol rotation value.

When a theme legend is completed, it can be saved as an ArcView legend file (.avl extension). In the data model, a legend file is named as per the theme/coverage file name. By default in ArcView, if a legend file exists with the same file name as a theme, when that theme is added to a view, the legend file is automatically loaded.

REVISED DRAFT NPS GEOLOGY-GIS DATA MODEL

As mentioned above, a standard geology-GIS data model has been developed for the National Park Service Geologic Resources Inventory (GRI). The model is based on ArcInfo and integrates with new user-friendly ArcView GIS software. As per ArcView and dBase requirements, database field names have been limited to ten characters or less. In addition, although many modern operating systems allow for long file names, theme/coverage file names within the model adhere to the 8.3 file name convention. Typically, themes/coverages and associated table file names are seven characters in length. The use of only seven characters allows for an additional character to be appended to a coverage name for related look-up tables. For an NPS unit digital geologic map, the first four characters or prefix of a coverage name (CODE) are the NPS unit's alpha code. The next three characters (suffix) abbreviate the type of geologic coverage (COV). As mentioned above, for INFO look-up tables associated with a coverage, an additional or eighth character, typically an integer, is appended to the theme/coverage name. An exception to the file naming convention presented above is arc/line map features of a polygon theme/coverage. ArcInfo allows for both arc/line and polygon labels to exist within the same (polygon) coverage, however, ArcView does not. Thus two themes are needed to present both the arc/line and polygon attribution of an ArcInfo polygon coverage in ArcView. For an ArcView arc/line theme associated with a polygon coverage, an 'A' (arc) is appended to the seven character polygon file name.

As with any digital map model, alterations and additional components, many derived from unique or uncommon map components, continue to advance and expand the model.

GEOLOGIC THEMES

The NPS geology-GIS model's data themes or coverages are listed below.

CODEGLG	poly/line	Map units or main geologic spatial data containing both polygon data describing the map units and linear data describing the interface between those units.
CODEGLN	line	Map units or main geological satial data
CODEGPT	point	Map units or main geological spatial data represented as points due to map scale limitations.
CODEFLT	line	Faults.
CODEFLD	line	Linear fold axes/hingelines.
CODEATD	point	Attitude observation points.
CODEDAT	point	Age-date sample location points (fossil or radiometric age estimates) .
CODEVNT	point	Volcanic vents, eruptive centers, features mapped as points.
CODEVLN	line	Linear volcanic crater, eruptive and flow features.
CODEDKE	line	Individual lithologic dikes.
CODEDKS	poly/line	Areas of lithologic dikes too numerous to map as individual segments (e.g. dike swarms).
CODEMIN	point	Mine and mining related features.
CODESEC	line	Cross section lines.
CODEASH	poly/line	Volcanic ash map units containing both polygon data describing the map units and linear data describing the interface between those units.
CODEMET	line	Metamorphic grade boundaries.
CODEMOR	line	Linear glacial moraine features.
CODEJLN	line	Linear joint features.
CODELN#	line	Contour and other lines.
CODESPF	point	Geologic point data deemed sensitive by NPS Unit.

# denotes a number assigned to theme/coverage name.

COVERAGE DATA DICTIONARY

At present, all of the 19 themes/coverages presented in the data model have been evaluated and adapted into a coverage data dictionary. Of note, each theme/coverage has several attribute fields that ArcInfo adds automatically to coverage. For polygon and point coverages, AREA, PERIMETER, CODECOV# and CODECOV-ID are added to the coverages polygon attribute table (.pat) . For arc/line coverages and polygon coverage arc/line attribution, FNODE#, TNODE#, LPOLY#, RPOLY#, CODECOV# and CODECOV-ID are added to the coverages arc attribute table (.aat). As noted within a coverage's FIELD DESCRIPTION /COMMENTS, several of these ArcInfo attribute field names are changed upon conversion to a ArcView (.shp) shape file.

To limit the length of this paper, only four data model themes/coverages are presented. In addition to the themes presented, two INFO look-up tables relating to map source information (CODEMAP) and additional lithology unit data (CODEGLG1) are also presented. Figure 1 illustrates relationships among data model themes/coverages presented in this paper to INFO and dBase database tables and the Windows Help File System (CODEGLG.HLP).

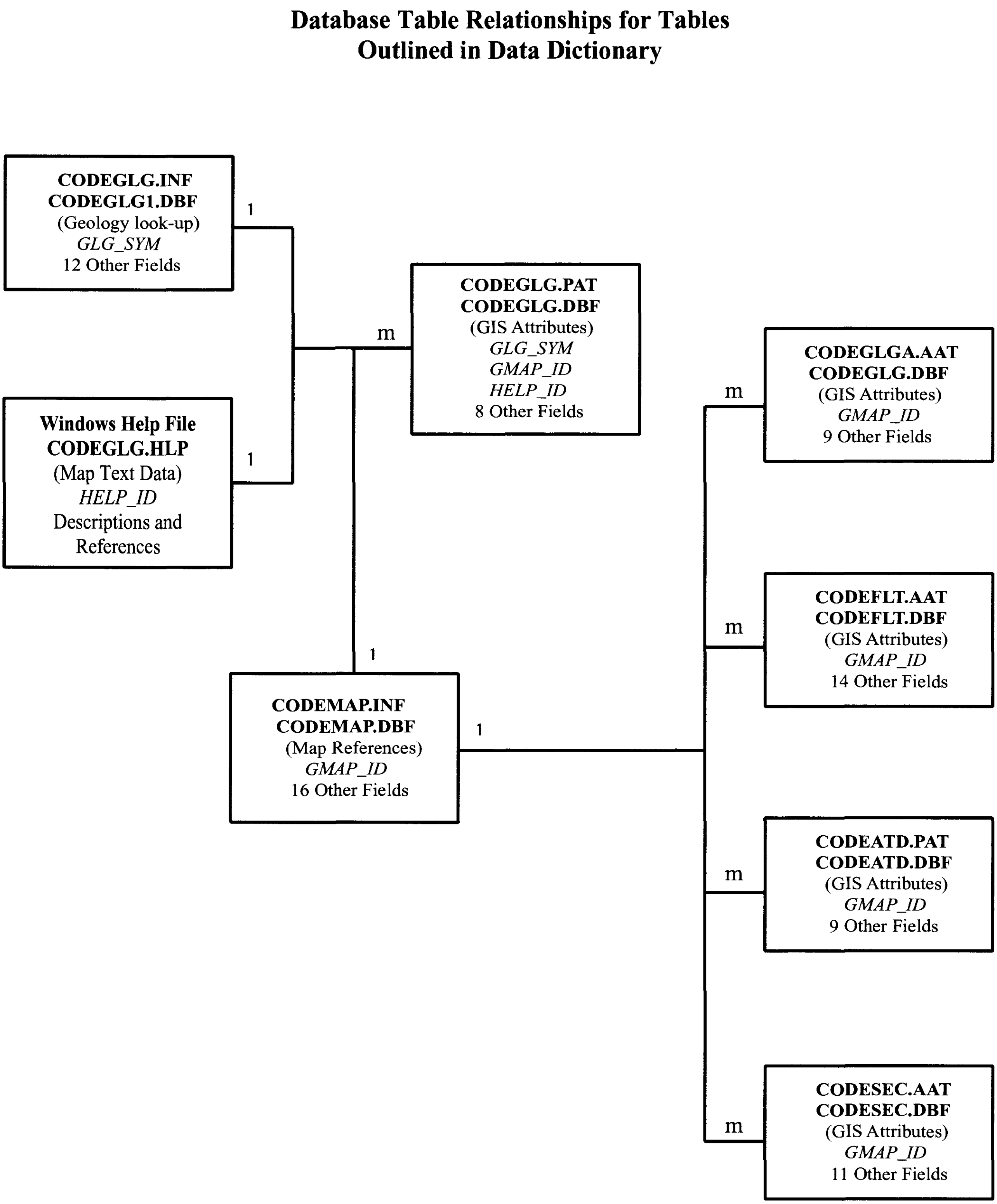

Figure 1. Simplified relationships among database tables presented in data dictionary. Bold type denotes database file names for ArcInfo (top) and ArcView (below). The tabular relationships are coded with "m" for many, and "1" for one. Related field or key names are in italics. Table types are in parentheses.

SPATIAL THEME (FILENAME): Area Geologic Map Units (CODEGLG)
THEME DESCRIPTION: Polygon and Arc/line coverage(s)
TABLE COVERAGE/FILE NAME:CODEGLG.PAT (ArcInfo), CODEGLG.DBF (ArcView)
TABLE FORMAT: INFO table (ArcInfo), dBase IV (ArcView)
NUMBER OF FIELDS: 10

FIELD NAME	TYPE-WIDTH	FIELD DEFINITION
AREA	F-4	area of the polygon
PERIMETER	F-4	perimeter of the polygon (in map units)
CODEGLG_	B-4	unique internal (PAL) sequence number for each polygon, ArcInfo CODEGLG#, converted in shape file .dbf
CODEGLG_ID	B-4	sequence ID-number for each polygon, ArcInfo CODEGLG-ID, converted in shape file .dbf
GLG_IDX	I-6	user-defined ID-number for each polygon
GLG_SYM	C-12	age-lithology unit symbol, used to relate coverage with the CODEGLG1.INF look-up table
USGS_SYM	C-12	geologic symbol from USGS geologic map(s)
GLG_AGE_NO	N-7.4	number to age-sort units in legend
GMAP_ID	I-6	unique number that relates map feature to series and citation information in CODEMAP.INF look-up table
HELP_ID	C-12	code (code typically GLG_SYM value) used to link to associated geologic text in Help File System

SPATIAL THEME (FILENAME): Geologic Map Unit Boundaries/Contacts (CODEGLG (ArcInfo)/ CODEGLGA (ArcView)
TABLE COVERAGE/FILE NAME: CODEGLG.AAT (ArcInfo), CODEGLGA.DBF (ArcView)
TABLE FORMAT: INFO table (ArcInfo), dBase IV (ArcView)
NUMBER OF FIELDS: 11

FIELD NAME	TYPE-WIDTH	FIELD DEFINITION
FNODE_	B-4	internal number of arc segment From Node, ArcInfo FNODE#, converted in shape file .dbf
TNODE_	B-4	internal number of arc segment To Node, ArcInfo TNODE#, converted in shape file .dbf
LPOLY_	B-4	internal left polygon number of arc segment, ArcInfo LPOLY#, converted in shape file .dbf
RPOLY_	B-4	internal right polygon number of arc segment, ArcInfo RPOLY#, converted in shape file .dbf
LENGTH	F-4	length of arc segment
CODEGLG_	B-4	unique internal sequence, ArcInfo CODEGLG#, converted in shape file .dbf
CODEGLG_ID	B-4	sequence ID-number for each polygon, ArcInfo CODEGLG-ID, converted in shape file .dbf
GLGCNT_IDX	I-6	user-defined ID-number for each arc segment
GLGCNT_TYP	I-2	code value for type of polygon (contact) boundary*
FLTCNT	C-1	flags lithologic contacts that are also faults*
GMAP_ID	I-6	unique number that relates map feature to series and citation information in CODEMAP.INF look-up table

* see Field/Attribute Code Value Lists below

FIELD/ATTRIBUTE CODE VALUE LISTS:

GLGCNT_TYP (polygon boundary/geologic contact type code)

1	known location
2	approximate location
3	concealed
4	queried
5	approximate location, queried
6	concealed, queried
7	inferred location
8	scratch boundary
9	gradational boundary
10	quadrangle boundary
11	extent/map boundary
12	shoreline
13	shoreline, approximate
14	ice boundary
15	ice boundary, approximate

FLTCNT (contact a fault?)

Y	Yes, the lithologic contact is also a fault.
N	No, the lithologic contact is not also a fault.

Special Note: A contact arc segment that is also a fault (FLTCNT = 'Y') has the down-thrown block on the right side of the arc. Thus, the down-thrown fault-block should be the arc segment's RPOLY_.

SPATIAL THEME (FILENAME): Geologic Faults (CODEFLT)
THEME DESCRIPTION: Arc/line coverage
TABLE COVERAGE/FILE NAME: CODEFLT.AAT (ArcInfo), CODEFLT.DBF (ArcView)
TABLE FORMAT: INFO table (ArcInfo), dBase IV (ArcView)
NUMBER OF FIELDS: 15

FIELD NAME	TYPE-WIDTH	FIELD DEFINITION
FNODE_	B-4	
TNODE_	B-4	
LPOLY_	B-4	
RPOLY_	B-4	
LENGTH	F-4	length of arc segment
CODEGLG_	B-4	unique internal sequence, ArcInfo CODEFLT#, converted in shape file .dbf
CODEGLG_ID	B-4	sequence ID-number for each polygon, ArcInfo CODEFLT-ID, converted in shape file .dbf
FLT_IDX	I-6	user-defined ID-number for each arc,
FLT_SEG_N	I-3	number for each fault segment
FLT_SEG_T	I-2	code value used to differentiate fault segment line types*
FLT_TYPE	I-2	code value for type of fault offset/displacement*
FLT_LT	I-3	fault and line segment type code value used for line representation*
FLTCNT	C-1	flags faults that are also contacts*
FLT_NM	C-60	fault name, if any, common to all arc segments with the same FLT_IDX.
GMAP_ID	I-6	unique number that relates map feature to series and citation information in CODEMAP.INF look-up table

* see Field/Attribute Code Value Lists below

FIELD/ATTRIBUTE CODE VALUE LISTS:

FLT_SEG_T (geologic fault segment line type code)

1	known location
2	approximate location
3	concealed
4	queried
5	approximate location, queried
6	concealed, queried
7	inferred location

FLT_TYPE (fault offset/displacement type code)

1	thrust fault
2	reverse fault
3	low angle normal fault
4	normal fault
5	right lateral strike-slip fault
6	left lateral strike-slip fault
7	reverse right lateral strike-slip fault
8	reverse left lateral strike-slip fault
9	normal right lateral strike-slip fault
10	normal left lateral strike-slip fault
11	unknown offset/displacement

FLT_LT (line type code)

11	thrust fault
12	thrust fault, approximate location
13	thrust fault, concealed
14	thrust fault, queried
15	thrust fault, approximate location, queried
16	thrust fault, concealed, queried
17	thrust fault, inferred location
21-137	as per FLT_TYPE concatenated with FLT_SEG_T

FLTCNT (fault also a contact?)

Y	Yes, the fault is also a contact between different map units.
N	No, the fault is not a contact between different map units

Special Note: A fault arc segment (FLTCNT = 'Y') has the down-thrown block on the right side of the arc. Thus, the down-thrown fault-block should be the arc segment's RPOLY_.

SPATIAL THEME (FILENAME): Attitude Observation Points (CODEATD)
THEME DESCRIPTION: Point Coverage
TABLE COVERAGE/FILE NAME: CODEATD.PAT (ArcInfo), CODEATD.DBF (ArcView)
TABLE FORMAT: INFO table (ArcInfo), dBase IV (ArcView)
NUMBER OF FIELDS: 10

FIELD NAME	**TYPE-WIDTH**	**FIELD DEFINITION**
AREA	F-4	
PERIMETER	F-4	
CODEATD_	B-4	internal number for each point, ArcInfo CODEATD#, converted in shape file .dbf.
CODEATD_ID	B-4	sequence ID-number for each point, ArcInfo CODEATD-ID, converted in shape file .dbf.
ATD_IDX	I-6	user-defined ID-number for each point

FIELD NAME	TYPE-WIDTH	FIELD DEFINITION
ATD_TYPE	I-2	code value for type of attitude measurement*
ATD_ST	I-3	azimuth of strike or trend, (0-359) degrees clockwise from the north with dip direction clockwise from strike direction (right-rule method). Non-applicable strike values assigned a value of 999.
ATD_DP	I-2	dip or plunge degrees from horizontal
ATD_AV_ROT	I-3	ArcView symbol rotation value field, used for symbol presentation
GMAP_ID	I-6	unique number that relates map feature to series and citation information in CODEMAP.INF look-up table

* see Field/Attribute Code Value Lists below

FIELD/ATTRIBUTE CODE VALUE LISTS:

ATD_TYPE (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	horizontal beds
5	strike and dip of beds, tops known from sedimentary structures
6	strike and dip of overturned beds, tops known from sedimentary structures
7	strike and dip of beds, tops known from sedimentary structures, dot indicates top of beds
8	strike and dip of variable bedding
9	approximate strike and dip of beds
10	strike of beds, dip amount unspecified
11-73	additional attitude point features types

SPATIAL THEME (FILENAME): Cross Section lines (CODESEC)
THEME DESCRIPTION: Arc/line coverage
TABLE COVERAGE/FILE NAME: CODESEC.AAT (ArcInfo), CODESEC.DBF (ArcView)
TABLE FORMAT: INFO table (ArcInfo), dBase IV (ArcView)
NUMBER OF FIELDS: 12

FIELD NAME	TYPE-WIDTH	FIELD DEFINITION
FNODE_	B-4	
TNODE_	B-4	
LPOLY_	B-4	
RPOLY_	B-4	
LENGTH	F-4	length of arc segment
CODESEC_	B-4	unique internal sequence, ArcInfo CODESEC#, converted in shape file .dbf
CODESEC_ID	B-4	sequence ID-number for each polygon, ArcInfo CODESEC-ID, converted in shape file .dbf
SEC_IDX	I-6	unique ID-number for each cross section line
SEC_ABV_O	C-6	initial cross section abbreviation on geologic map
SEC_ABV	C-6	cross section abbreviation on digital map
SEC_FILE	C-60	file directory path and graphics file name of cross section .jpg file (ex. d:\gis-blca\graphics\I584a.jpg)
GMAP_ID	I-6	unique number that relates map feature to series and citation information in CODEMAP.INF look-up table

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ACCESSORY DATA FILES

Additional data on unit lithology and source map information are included in two look-up tables that are related to map coverages through a primary or secondary key field.

TABLE COVERAGE/FILE NAME: CODEGLG1.INF (ArcInfo), CODEGLG1.DBF (ArcView)
TABLE FORMAT: INFO table (ArcInfo), dBase IV (ArcView)
NUMBER OF FIELDS: 11

FIELD NAME	TYPE-WIDTH	FIELD DEFINITION
GLG_SYM	C-12	age-lithology unit symbol, used to relate the coverage with the CODEGLG1.INF or CODEGLG1.DBF
GLG_NAME	C-100	formal name of map unit, if any
G_REL_AGE	C-5	relative age of geologic units
G_SSCR_TXT	C-6	subscript from the map symbol
GLG_AGE_NO	N -7.4	number to age-sort map units in legend
G_AGE_TXT	C-50	geologic time period of map unit
G_MJ_LITH	C-3	code value for lithologic type*
G_LITH_ID	I-10	code value used to describe lithology
G_LITH_TXT	C-100	brief text describing lithology
G_NOTE_TXT	C-254	descriptive notes about the map unit
GMAP_SRC	C-100	source map(s) with organization and map series number (i.e. USGS GQ-1402, USGS GQ-1568)

* see Field/Attribute Code Value Lists below

FIELD/ATTRIBUTE CODE VALUE LISTS:

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 CODEGLG1.INF or CODEGLG1.DBF

GLG_SYM = Qvba(pc)
GLG_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_ID = 71
G_LITH_TXT = basaltic andesite flows
G_NOTE_TXT = volcanic lava flows with interbedded soil horizons
GMAP_SRC = I-757; GQ-1082

TABLE COVERAGE/FILE NAME: CODEMAP.INF (ArcInfo), CODEMAP.DBF (ArcView)
TABLE FORMAT: INFO table (ArcInfo), dBase IV (ArcView)
NUMBER OF FIELDS: 18

FIELD NAME	TYPE-WIDTH	FIELD DEFINITION
GMAP_ID	I-6	unique ID-number of map citation
GMAP_PARK	C-30	list of NPS Unit alpha codes map is relevant to
GMAP_CODE	C-4	unique 4-letter abbreviation code of map
GMAP_ABBRV	C-150	abbreviation of map title, often includes map name and interpretation technique (e.g., Preliminary) and/or a map emphasize term on the distribution of specific materials (e.g., Surficial).
GMAP_YEAR	I-4	compilation or publication year
GMAP_AUTH	C-254	map author(s)
GMAP_ORG	C-100	organization that created or compiled the map
GMAP_TITLE	C-200	complete map title
GMAP_SER	C-40	map series or organizational identifier (e.g., USGS GQ-1516)
GMAP_SCALE	I-7	source map scale denominator
GMAP_PROJ	C-100	name or description of map projection with projection datum
GMAP_REF	C-254	complete map citation in USGS style
GMAP_DESC	C-254	brief description of the map
GMAP_XMAX	F-8.6	western limit of map in decimal degrees
GMAP_XMIN	F-8.6	eastern limit of map in decimal degrees
GMAP_YMAX	F-8.6	northern limit of map in decimal degrees
GMAP_YMIN	F-8.6	southern limit of map in decimal degrees
GMAP_SRC	C-100	source map(s) with organization and map series number (i.e. USGS GQ-1402, USGS GQ-1568)

Example record for the Geologic map of Rocky Mountain National Park and Vicinity, Colorado. The 4-letter NPS alpha code for Rocky Mountain NP is ROMO.

ROMOMAP.INF or ROMOMAP.DBF

GMAP_ID = 144
GMAP_PARK = ROMO
GMAP_CODE = ROMO
GMAP_ABBRV = Rocky Mountain NP
GMAP_YEAR = 1990
GMAP_AUTH = Braddock, William A., and Cole, James C.
GMAP_ORG = USGS
GMAP_TITLE =Geologic map of Rocky Mountain National Park and Vicinity, Colorado
GMAP_SER = I-1973
GMAP_SCALE = 50000
GMAP_PROJ = Geographic
GMAP_REF = Braddock, William A., and Cole, James C., 1990, Geologic map of Rocky Mountain National Park and Vicinity, Colorado, USGS, I-1973, 1:50,000 scale
GMAP_DESC = Geologic map of Rocky Mountain National Park and adjacent vicinity.
GMAP_XMAX = -105.958333
GMAP_XMIN = -105.458333
GMAP_YMAX = 40.566666
GMAP_YMIN = 40.125000
GMAP_SRC = see published USGS non-digital (paper) map.

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Limitations in the Use of Map Geometry as the Foundation for Digital Geologic Database Design

By Michele E. McRae

U.S. Geological Survey
National Center, MS 926A
12201 Sunrise Valley Drive
Reston, VA 20192
Telephone: (703) 648-6349
Fax: (703) 648-6953
e-mail: mmcrae@usgs.gov

INTRODUCTION

For most of the last century, analog maps have been the geologists' primary instrument to communicate their understanding of the geologic environment. These products have proven their utility in a wide variety of societal and scientific applications such as natural hazards mitigation, water and resource management, and land-use planning. With the advent of geographic information systems (GIS) technology and its improved ability to integrate diverse geospatial data, the digital database is now challenging the role of the traditional geologic map.

Digital datasets facilitate many map-oriented activities such as updating and reprinting existing maps, rescaling data, recombining map units based on common attributes, and overlaying geologic data with other geographic information. Of course, these technological advances have altered neither our understanding of geologic information nor its role in decision-making. Since geologic maps have proven their ability to effectively communicate knowledge of geologic environment, database design practices have focused on translating the geologic map model into the digital arena so that individual paper map elements (i.e., lines, polygons, and symbols) become the geometric building blocks of their corresponding digital database.

However, a digital database is not a map. Although applicable to the same problems, the publication media and methods of presenting, exploring, visualizing, and analyzing digital data are significantly different. These differences directly impact how the user perceives and applies the information. Consequently, a digital database whose geometry adheres strictly to the conventions of a paper map is less effective at communicating information than its analog counterpart. This paper attempts to characterize these differences and to suggest alternative models for database design.

THE GEOLOGIC MAP

In order to improve digital database design, we first need to understand how data is modeled on a geologic map and how one perceives that model. Bernknopf and others (1993), define a geologic map as "a graphical information display that uses a combination of colors, lines, and symbols to depict the composition and structure of geologic materials and their distribution across and beneath the landscape. The graphical display contains both *descriptive information* about geologic units and structures and an *interpretive model* of how they were formed. This combination of descriptive and interpretive geologic map information provides a conceptual framework that relates all the geologic elements of an area together so that the position, characteristics, and origin of each element are understood in relation to all other elements." The scientific content that one expects to find includes physical and chemical properties of rock units, three-dimensional geometry, relative age relationships, and relationships between geologic structures and processes. The primary graphic components of geologic maps are a planimetric view of the distribution of rock units at the Earth's surface (the map itself) and a legend. Additional graphic elements include a variety of cross-sections, fence diagrams, stratigraphic sections, correlation diagrams, etc.

This combination of individual, 2-dimensional graphic elements forms a single, cohesive product. In order to correctly apply geologic map information, one must understand that the geographic relationships of geologic units are not fixed, but rather change with depth below or height above the Earth's surface. The user must understand how to reconstruct the 3-dimensional framework from these components. Since this interpretation is largely visual, it is the author's responsibility to maximize this understanding by controlling the selection of graphic elements, their layout, and symbolization.

THE DIGITAL DATABASE

Contents of geologic databases vary widely, but generally include a graphic representation of the distribution of geologic features and tabular information describing properties of those features. The graphic elements within a GIS are georeferenced, so that an exact coordinate for any feature (or part of a feature) can be obtained. The locations of objects with respect to each other are understood in terms of these coordinates. For this reason, the positional accuracy of features is of prime importance in the development of any GIS database.

Current database development practices focus mainly on the map and legend components of the paper map. Typically, an existing paper map is scanned or digitized, separated into thematic layers, and attributed according to the map legend information. Due to the importance of positional accuracy, a great deal of effort is expended in 'quality control', i.e., ensuring that the source map's lines and polygons are accurately reproduced and attributed consistently. Although the cross-sections and other diagrams are often included as graphics files, they receive less attention. Consequently, the finished product accurately reproduces the map geometry and descriptive content, but with less emphasis on the interpretive information and geologic relationships.

THE PAPER MAP MODEL AND THE DIGITAL DATABASE

Many components of geologic maps are represented in digital databases. However, the product as a whole lacks the visual cohesiveness of the parent product. Although there is a visual component to GIS, the tools for exploring, querying, and analyzing digital data are not as visually oriented. GIS interprets geographic distribution and relationships through coordinate information and geometry. Consequently, database models must encode geologic relationships within this context.

This section outlines two conceptual issues that need to be addressed in order to improve geologic knowledge representation in digital databases: thematic separation of data layers and the geometric representation of geologic objects. (Note: For the purposes of this discussion, the terms 'feature' and 'object' have distinct meanings. An object generally refers to an entity that is identifiable by particular physical characteristics, relationships, and behaviors, while the term 'feature' generally refers to the geometric element used to represent that object.) Each issue is discussed separately, although in practice, they are interrelated and difficult to isolate. The context of this discussion is conceptual rather than practical; however, two recent publications (McRae, 1999; and Cannon, McRae, and Nicholson, 1999) provide some examples of how existing GIS tools and data structures can be implemented to address the issues presented here.

Thematic Separation of Related Geologic Features

Digital databases are frequently published as a series of files that contain different geologic 'themes'. Thematic separation is usually dictated by feature type (i.e., point, line or polygon) rather than by the geologic relationships between objects. For example, since faults are usually modeled as lines and geologic units as polygons, they are often placed in separate data layers. On a geologic map, of course, faults that act as geologic contacts would be represented by a single line segment and symbolized accordingly. Conceptually, this is an instance of a single feature having two functions (i.e., that of fault and contact). By placing faults and contacts in separate coverages, each function is effectively represented by a unique feature. This obscures the geologic interpretation. Further, database size is negatively impacted by unnecessarily maintaining the same feature in two separate data layers.

On a geologic map, the author controls the physical layout of individual components in order to facilitate the visual interpretation of the geologic relationships. Current database design practices require the user to reassemble individual components in some meaningful way. Recent policies adopted by the USGS have attempted to overcome this problem by recommending that a print quality graphic file of the geologic data be included with each dataset. This provides the database user with the opportunity to view the data as the author intended. Although this is a valuable visual reference, the issue of how to encode the author's interpretation within the database structure still needs to be addressed.

Cartographic Features Versus Geologic Objects

According to the geologic map data model (Johnson and others, 1999) adopted by the North American Data Model Steering Committee (http://geology.usgs.gov/dm), geologic objects in a database can be either singular or compound. Singular objects are said to be those that have been observed at a single location or are represented by a single cartographic feature. Compound objects are said to result from the interpretation or classification of multiple observations at multiple locations, such as a fault consisting of individual fault traces observed at multiple outcrops.

The data model treats singular and compound objects differently. The geometry of singular geologic objects is stored directly in the Spatial Object Archive, while the geometric representation of compound objects must be formed by the aggregation of multiple features within the Spatial Object Archive. Although implementation details are left to the database designer, the examples cited in the data model generally use cartographic representation as the basis for modeling an object as singular or compound. This convention has been widely adopted in the production of digital databases.

A negative consequence of this practice is that what the geologist considers "singular" can become "compound" due to either the limitations of its analog geometry or the digitization process. For example, consider the case of a fault that has been offset by another. The geologist views the crosscutting fault as a singular object and the offset fault as a compound object consisting of two line segments. However, some GIS software packages place nodes at all line intersections. Consequently, both faults will be divided into multiple line segments, effectively creating two compound objects. Without some mechanism to 'reassemble' the crosscutting fault's segments back into a single feature, the geologic interpretation is obscured. Similar problems occur with polygonal data. Paper map constraints force geologic units to appear mutually exclusive, so that their cartographic representation reflects only that portion of the unit not covered by another. On a geologic map, a volcanic unit that underlies a sedimentary unit may appear as multiple, disjointed polygons where the sedimentary unit has eroded to expose it. Common symbolization, annotation, and accompanying cross-sections help inform the map user that the unit is contiguous at depth. Current database production practices typically digitize and attribute each polygon individually. Again, this fragmentation obscures the geologic interpretation that the individual exposures are really part of a single, underlying unit.

In some cases, an object's cartographic representation may serve as the foundation for its digital geometry, if combined with the appropriate data structure. The behavior of the crosscutting fault, for example, can be modeled by using network geometry to aggregate the individual line segments into a single feature. However, many cartographic representations fail to reflect the real geographic extent of the objects being modeled. This is particularly true for geologic units. For example, the aggregation of the volcanic unit's individual polygons would still misrepresent the geologist's knowledge of its distribution.

On a geologic map, any knowledge of the distribution or understanding of how one geologic unit relates to another will be based on an individual's ability to interpret the 3-dimensional distribution from the 2-dimensional representation. A GIS can interpret the distribution of an object only through coordinate information and geometric properties. Hence, the 3-dimensional framework must be encoded in a way interpretable by GIS software. A key to accomplishing that is to ensure that the geometry of an object fully reflects the geologist's knowledge of its distribution. In many cases, that will involve a geometry not constrained by an object's cartographic representation.

CONCLUSIONS

A recent article states, "With the adoption of GIS, many analog records have been computer encoded without considering the limitations of the underlying analog-oriented conceptual models. The result may be an accurate encoding of analog records, but it rarely will be a comprehensive model of reality given the inherent limitations of analog records... The new geospatial data management paradigm is about creating meaningful models that effectively capture the geographic knowledge that defines an organization's version of reality. It's much less about maps or how to convert all those old analog records in the back room." (Levinsohn, 2000). GIS also has its limitations, particularly in its ability to model true 3-dimensional relationships. However, technological advances continually provide new tools for the modeling, visualization, analysis, and publication of spatial data. As GIS tools continue to evolve, so will our ability to model the behavior and relationships of the geologic environment. Despite these advances, a paper map model continues to dominate the design and production of geologic databases. Although geologic maps have been effective tools for communicating geologic data, they are an ineffective model for digital data. The unique properties and constraints of GIS must be considered in developing databases that adequately model our knowledge of the geologic world.

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Geomatter II : A Progress Report

By Eric Boisvert[1], Vincent Desjardins[2], Boyan Brodaric[3], Brian Berdusco[4], Bruce Johnson[5], Kathleen Lauzière[1]

[1]Geological Survey of Canada
Quebec Geoscience Center
880 Ch. Ste-Foy
Québec, Québec, Canada, G1V 4C7
Telephone: (418) 654-3705
Fax: (418) 654-2615
e-mail: eboisver@nrcan.gc.ca, klauzier@nrcan.gc.ca

[2]Recrusoft
390, St-Valier Est, bureau 401
Québec, Canada G1K 3P6
e-mail: vdesjardins@recruitsoft.com

[3]Department of Geography,The Pennsylvania State University
302 Walker Building
State College, PA , USA 16802-5011
email: bmb184@psu.edu

[4]Ontario Geological Survey
Willet Green Miller Centre, Level B7
933 Ramsey Lake Rd
Sudbury, ON, Canada P3E 6B5
e-mail: brian.berdusco@ndm.gov.on.ca

[5]United States Geological Survey
954 National Center
Reston, VA, USA. 20192
e-mail: bjohnson@usgs.gov

INTRODUCTION

GeomatterII (Geologic Map Attributer - or Geoscience Map Attributer) is a data entry and editing tool to enable the management of NADM (North American Data Model) structured databases (Johnson and others, 1998). The NADM is the result of a joint effort between American and Canadian geoscience representatives from federal and state/provincial agencies. The steering committee of the group produced a series of logical models, the last being called "version 4.3" to structure map related geological information. The complexity of the model was seen as a problem for most geoscientists who have limited knowledge of database design and implementation.

Geomatter II has been developed to shield the casual user from database implementation details while still allowing expert users to extend and modify some parts of the database structure. It provides a graphical user interface where the map and associated information are displayed in a tightly-integrated application. The interface is built around a "selection state" engine, where every piece of information is highlighted/displayed according to the current selection. This selection can be triggered from various data controls within the interface (maps, datasheets, tree views, etc.) and all other components of the application will respond accordingly.

The first version of Geomatter (then called IGMDM, Interface for the Geological Map Data Model) was presented at the last DMT (DMT '99, Madison, WI) and a full description of the application is available in Brodaric and others (1999a). It was then a slightly clunky demo application, crippled with bugs and built to address a very specific data model version that was a little different from the, then current, v. 4.2 model. While this software could hardly be used in any serious application, it showed how an application could hide database complexity behind a friendly interface.

The United State Geological Survey (USGS), Ontario Geological Survey (OGS) and Geological Survey of Canada (GSC) funded another round of development to improve this prototype application to a version that can be used in a real project. Several technological and philosophical problems had to be addressed to create this application. For a discussion on the rationale behind Geomatter, the reader is referred to Brodaric and others (1999a). The logic of the application has been kept identical and effort has been concentrated on improvement of the prototype.

Software and Hardware

Geomatter is a stand-alone application that runs on Win9x/NT computers; it has not yet been tested on the Windows 2000 or Windows "me" (millennium edition) operating systems. The application is build around ESRI MapObjects 1.2 ActiveX and ODBC API. The code was written in Delphi 5 (Inprise/Borland). A blank MS Access 97 database following either v.4.3 structure or v.5.2 (Cordlink) structure is available with the application. The Cordlink data (Brodaric and others, 1999b) is an adaptation of the NADM to support a web-enabled virtual library. Geomatter uses ESRI shape files for its geospatial archives.

Geomatter follows in the footsteps of key NADM applications such as Curly (Raines and Hastings, 1998) and LegendMaker (Sawatzky and Raines, 1998). The application is available to NADM participants but cannot be widely distributed due to licensing issues of one of the internal component (MapObjects)

Hiding Database Complexity

The goal of the application is to hide the database complexity behind a user interface that presents the user a set of known concepts, such as a map, polygons, lines, points, legend items, etc. Geomatter is a "conceptual" representation of the database model (Brodaric and others, 1999a) , as understood by the data model designers. The application then communicates using a logical representation (using SQL) of the data model to interact with a physical implementation of the database (in MS Access).

DEVELOPMENTS AND IMPROVEMENTS

While this document is not intended to be a highly technical description of Geomatter, following are several brief highlights of GMII development and improvements. Instead of trying to patch up code in the original version, the application was rewritten, using what had been learned from the previous version. Several problems were due to the initial design of the application, while new challenges have been added by the new sets of specifications required by the stakeholders. The general layout of the application has not changed dramatically but the inner design is built around a more expandable "programming style" - or as it is called in the programmer circles; "design pattern". The appendix shows a series of "snapshots" to avoid cluttering the text with too many figures.

Abstraction of the Application

The most dramatic change in the application is the design pattern. The user interface is now shielded from the database structure, up to a certain point, by a specific software component (labeled API) in figure 4a and 4b. This means that minor changes in the data model (and, therefore, in the database) will not require changes in the application. These changes can be handled by changing the SQL commands that are physically located in the database in a special table.

The application is also somewhat shielded from parts of the interface since they behave as independent pieces of software. Additional interface segments can be added without interfering with other parts of the application. This design style was adopted in the earlier version, but the current version implements a more formal system.

The application is also built assuming a need for future changes. This flexibility allows the addition of new COA (Compound Object Archive) and SOA (Singular Objects Archive) related tables at will (see Johnson et al, 1998 for full description of COA and SOA concepts). Special data tables are created within the database to store application metadata, such as the list of tables that are to be filled by the user, what pick list to display, etc. This allows expansion of the data model to suit particular needs. To gain this flexibility, Geomatter must create forms on the fly from database content (figure 1), requiring the inclusion of a series of "System tables" within the database to store information needed by the application (this will be discussed in *"User defined database structure"*).

Script-Based Customization

When a new database is created, Geomatter connects to an empty data structure, which is provided with the application. When the connection is established, Geomatter performs a series of tests to identify a) what version of the database is being used, and b) if all system tables are available. System tables are specific tables that hold information about the variables parts of the database (i.e. COA related tables , such as Rock_Unit, Metamorphic_Unit, and SOA tables such as SOANames, SOAFossil, etc.). These tables also hold information about "Aliases". An Alias is human readable text that is displayed in a field instead of an id. Most foreign keys in the database are numerical ids that refer to information stored in other table. When a table is displayed to the user, this numerical key must be replaced by text fetched from the related table.

Hierarchical Legend Component

The legend component reflects the COA organization it is linked to. Legend items are displayed as a hierarchical tree where the COA hierarchy determines the locations of the legend items. Since a single legend item is related to a single COA, the tree structure of the legend simply reflects the COA's structure. It is not possible to alter the hierarchical organization of legend items (except when the legend is **not** associated with a COA). Altering the COA structure will be automatically reflected in the legend panel. It is also possible to "collapse" the legend tree to generalize the legend content. When a legend item is collapsed, the related spatial objects (on the map display) automatically use the parent symbolization (figure 2).

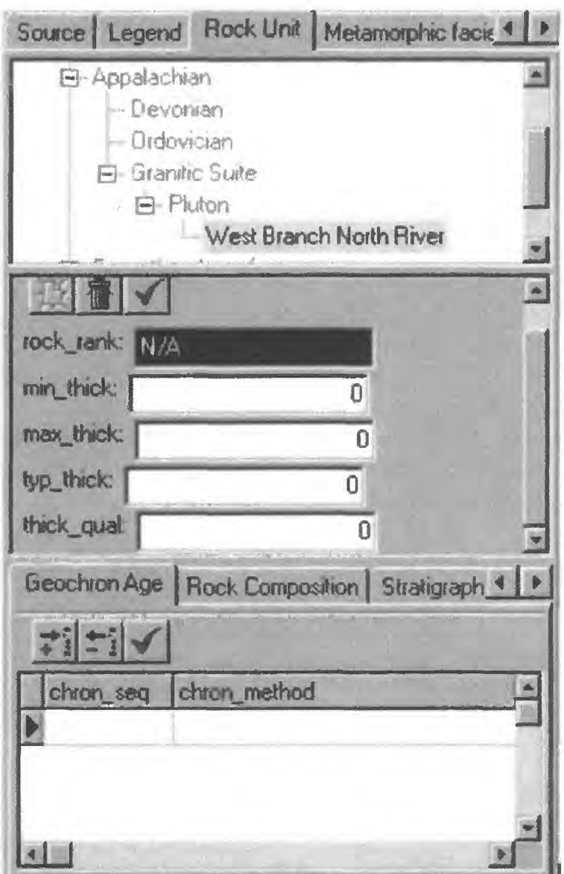

Figure 1. A typical data panel showing the COA navigator (top), a COA related table (middle) and all the related attribute tables (bottom).

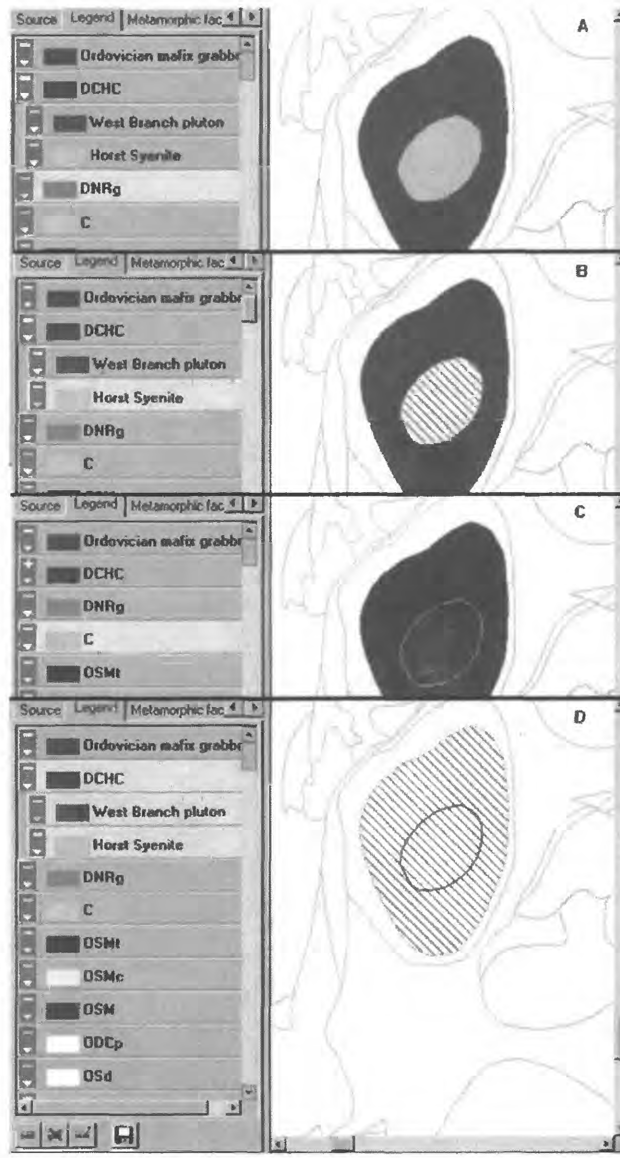

Figure 2. A) Legend in initial state, note hierarchical structure. B) sub-item selected, selection is highlighted in yellow (appears in a different shade of grey on the figure) in the legend and diagonal lines on the map. C) Legend sub-items collapsed into their parent, note map generalization. D) Selection of the parent while children are visible, children are automatically selected.

Legend items can be displayed in two forms, *expanded and contracted (figure 3)*. The expanded version shows all attributes of the legend (the *classification_object*). This was implemented to allow more than 3 or 4 items to be displayed simultaneously in the restricted area of a computer screen.

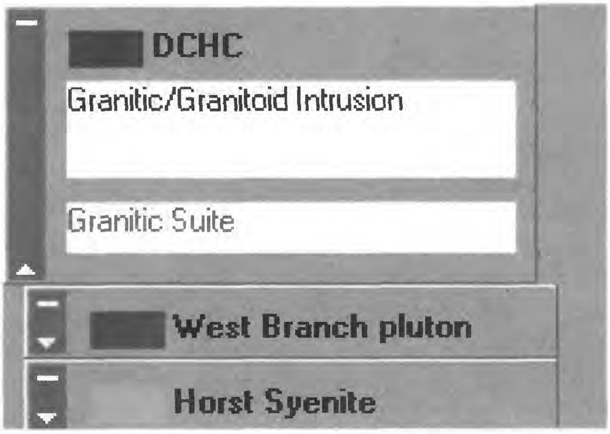

Figure 3. Legend items in different states. The parent (topmost) is in expanded form while the remaining are in contracted form.

Customizable Pick List

Several fields in the database must be filled with specific keywords to impose consistency. Keywords are located at different places within the database. They can either be references to other attribute tables (e.g. Source) or can be keyword tables that are used for this purpose only (e.g. Rock_Unit_Rank). Since the application can accommodate user defined tables, a mechanism to customize pick lists has also been implemented. This module has been the most complex part of the application to create because of the large number of variables to take into account. The pick list mechanism had to be able to handle both tree and linear structures, allow (or deny) users to add new items, thus leading to the ability of the pick list manager to launch other pick lists to populate themselves. The mechanism is built around the SYSDIX (System Dictionary) table that keeps information about every potential picklist. New picklists can be created by adding records to this table. Appendix figures 6,7 and 8 show pick lists.

Legend Builder

In many cases, the map to be attributed exists as a digital file that contains the necessary information to create a classification (legend items). It would be a major burden to re-attribute every line or polygon manually when this information was already available in the GIS file. A small tool has been included to automatically read information from the GIS file and create legend items. New legend items are not linked to any COA; this is left to the operator.

Abstracted Database Access

This topic can become very technical, and we will simply state that a lot of effort has been made to accommodate changes to the data. Two mechanisms have been used: 1- Usage of a SQL library, and 2- Modular design. Chances are that the first approach will be abandoned because its implementation and maintenance is too complicated. Geomatter I was restricted to a very specific implementation of the database and any changes required a rewrite of the application. Adding new tables to the data model to expand its data content to other concepts was simply not handled by the first version of the application (see next section). Figure 4 compares versions 1 and 2.

Figure 4 shows that all the SQL commands required to communicate with the database have been moved into the physical database (instead of being located within the application). This allows changes to be made to the SQL commands to adapt to slight changes of the data model. But this approach has its share of problems because this list of SQL commands is specific to each database implementation. Every change or correction to the application involving this list of SQL command brings a tedious process of updating both the application and the SQL commands on every version already installed. This is where backward compatibility problems start occurring. Any change of the SQL commands proves to be a very delicate task. A very deep understanding of how the data model and the application work was needed to do this. This design was chosen to allow users to alter the application's behavior and to adapt it to other versions of NADM. But the complexity of this task prevents anyone from trying this, except for the very adventurous.

The second method of abstraction is the use of a component approach for the design of the application. The application deals with a set of components written for a specific database structure. This is how Geomatter can accommodate version 5.2 (an adaptation of NADM for Virtual Libraries such as Cordlink). The application communicates with a "data-panel-that-handles-data-of-type-x" instead of dealing directly with data of type x (figure 5).

The application can then access various versions of the model by loading the appropriate modules.

User-Defined Database Structure

Another challenge of this version was to allow the user to add their own data tables and modify fields of existing data tables. For those familiar with the database structure, variable data tables are the COA tables (those attached to a COA concept, such as Rock_Unit and related tables such as lith_form) and the attributes attached to spatial objects (SOA tables). The application has to accom-

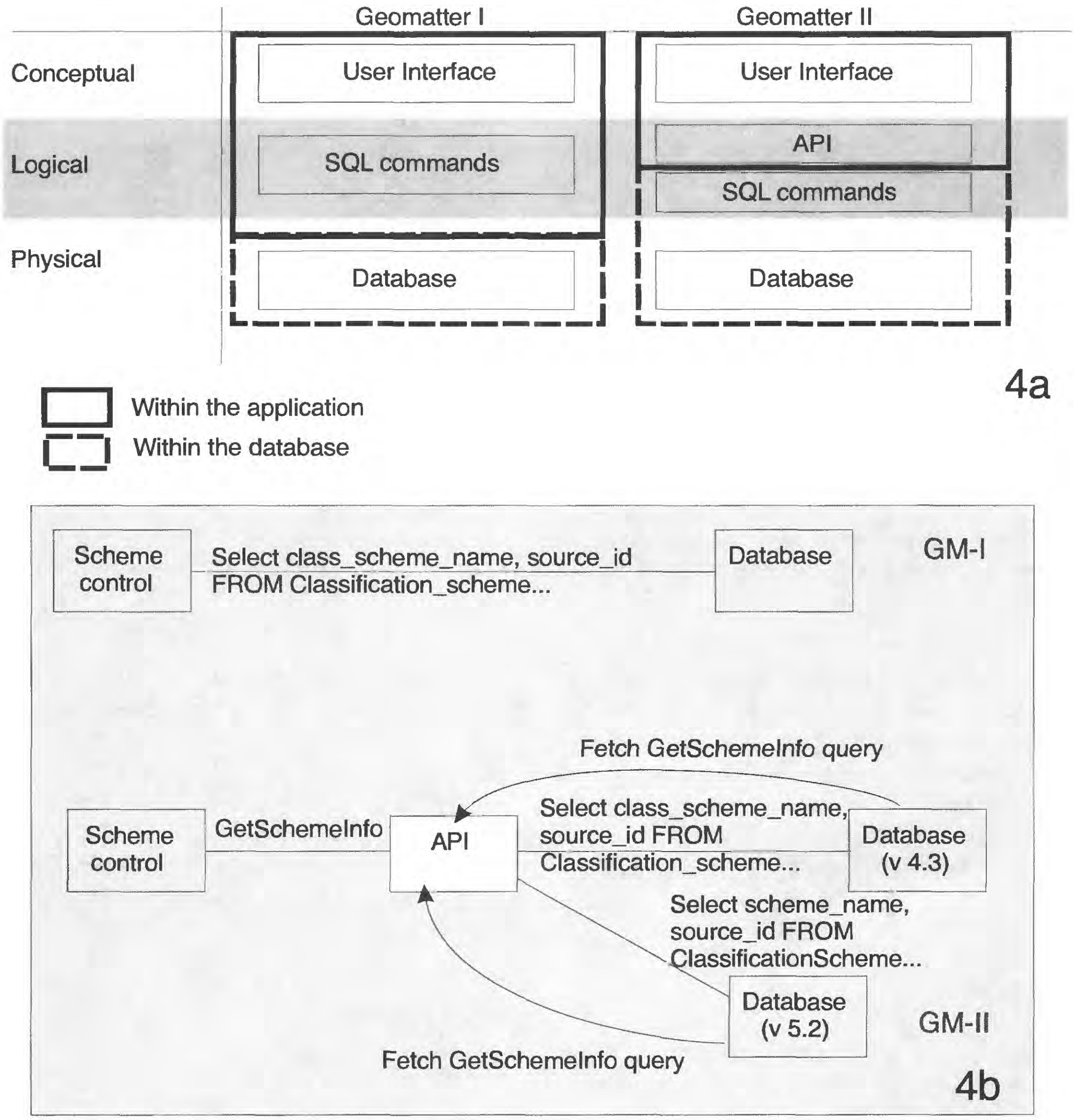

Figure 4. a) The logical (SQL) design of the application was "hard coded" into Geomatter I while it has been moved into the physical portion (i.e. in the database) for Geomatter II. b) The application now calls a specialized module (API) using a unique (conceptual) syntaxes, that is in turn converted into logical statements (SQL command), stored in the database with the data.

tables such as lith_form) and the attributes attached to spatial objects (SOA tables). The application has to accommodate a varying number of tables having various field lists, all of them potentially linked to various picklists and other attribute tables. This is basically what the data panel shows on figure 1 (and Appendix, figure 4). The top section is the COA tree (replicated on every data panel, it can be used to navigate or to edit by double clicking on it), the central section is the COA related table (e.g. Rock_unit) and the bottom part are attribute tables related to the central section. These panels are generated dynamically from the database content. The list of tables that can appear in the bottom panel is also located within the database and , thus, is customizable. The pick lists described in an earlier section allow access keyword lists on any of the fields.

FUTURE DEVELOPMENTS

The goal of Geomatter is to allow users to enter data into NADM compliant databases and support a certain level of browsing. The current version of Geomatter is aimed at manual map attribution; however, several modules could be very useful for converting maps into NADM. For instance, it is not possible from the current interface to import a large number of SOA entries into an existing

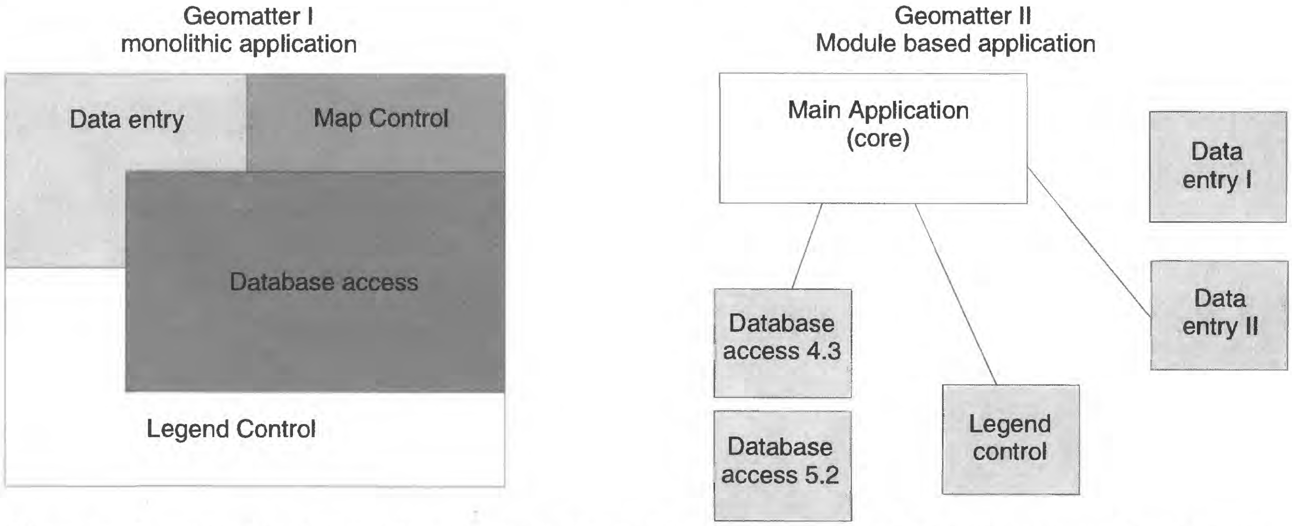

Figure 5. Geomatter I was a monolithic application where new controls required a lot of reprogramming. The new design allows new components to be added with less work.

sion of Cordlink for hydrogeology), some browsing tasks are delegated to a web interface. The application does not support multi-user access to the same database very well (actually, it relies on pure chance when connected to Access because it has an "optimistic" approach to table locking). So, areas of improvement in the short term should concentrate on import/export and multi-user capacities.

CONCLUSION

This current version, unlike its predecessor, is a workable application that is already in use in two internal projects at GSC-Québec. The usage of the tool so far is oriented towards web publication (where it is used in conjunction with other tools such as Cordlink ColdFusion+Mapguide engine) of hydrogeological information (Hydrolink) and geological information (GASL, or Geological Atlas of St-Lawrence valley). The goal of the tool is still single user codification of simple maps but the current design of the application allows others to build on top of current development and add more functionality rather easily (the Legend builder took a few hours to implement).

Geomatter II reached one of its goals when it was at its alpha stage during the winter of 1999-2000; it gave casual users access to NADM databases so they could experiment with them. This is exactly what happened within GSC-Québec and the rest of the GSC. Momentum was generated for use and adoption of the NADM when the application was demonstrated and people could actualy see what all those boxes on the NADM chart really meant.

ACKNOWLEDGEMENT

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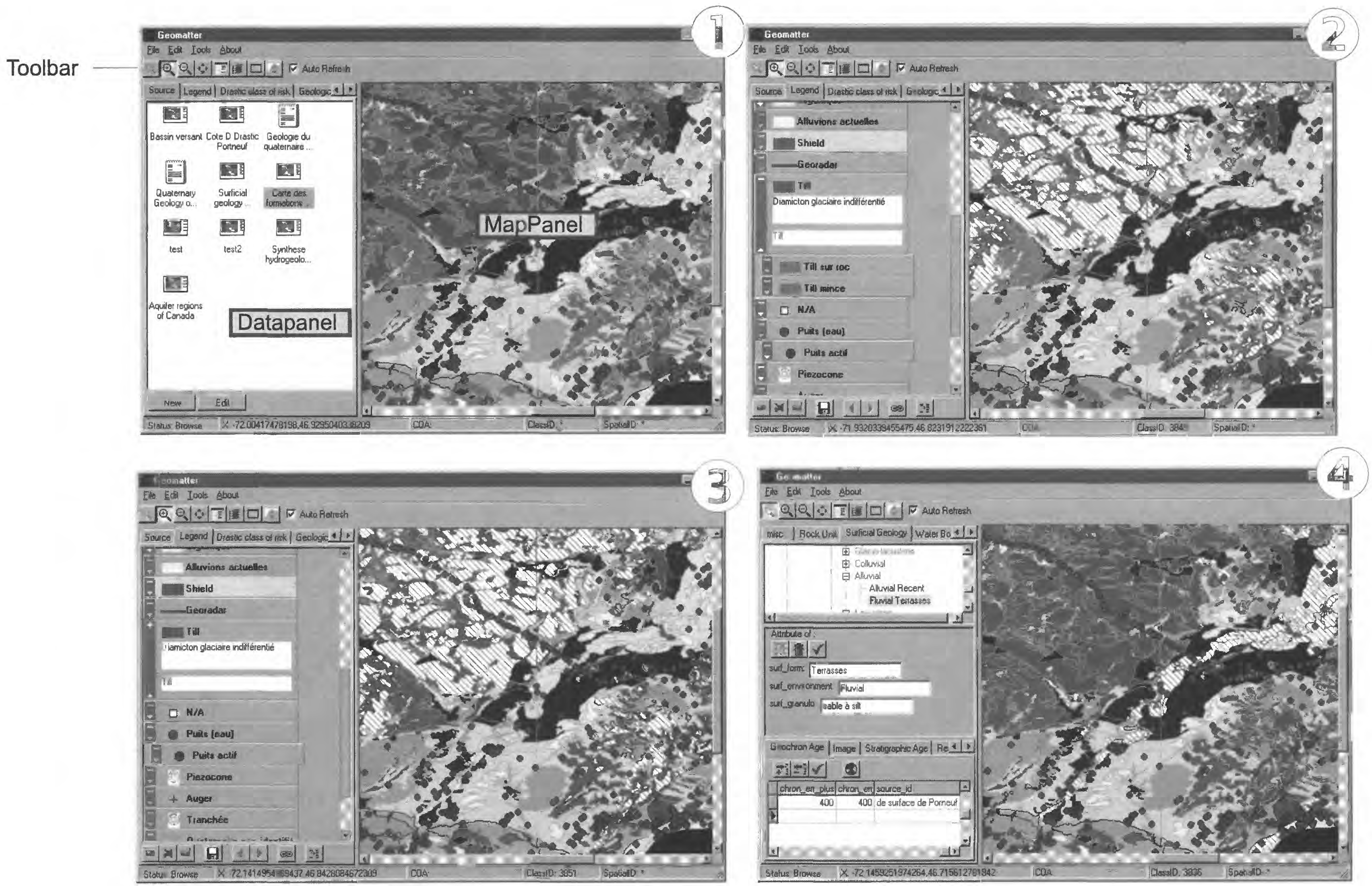
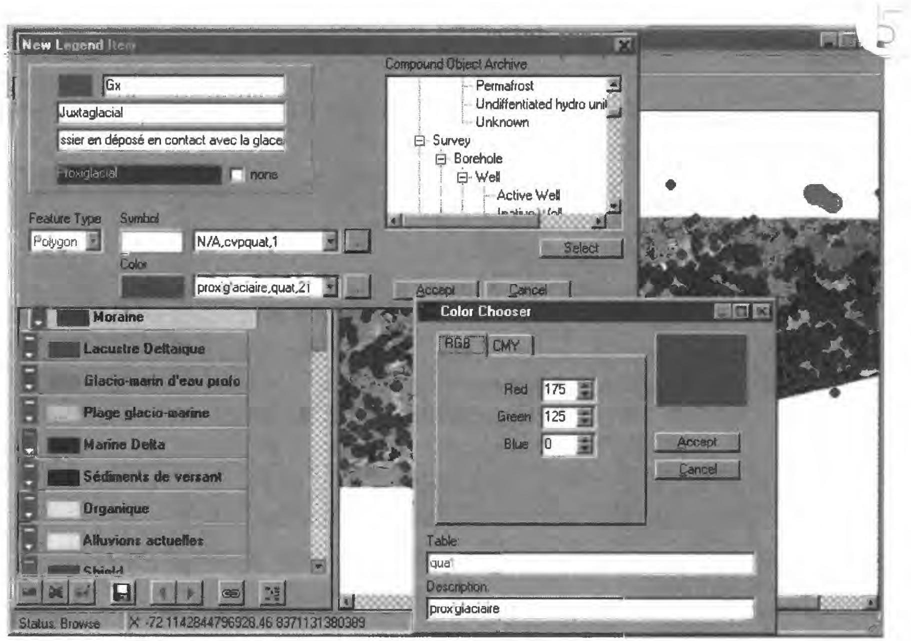
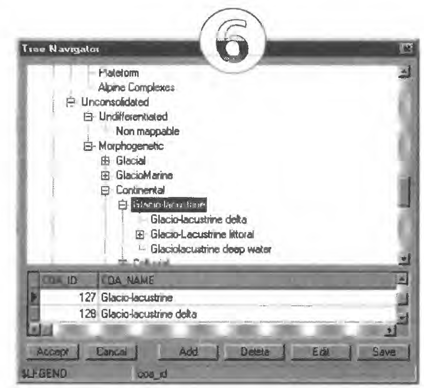
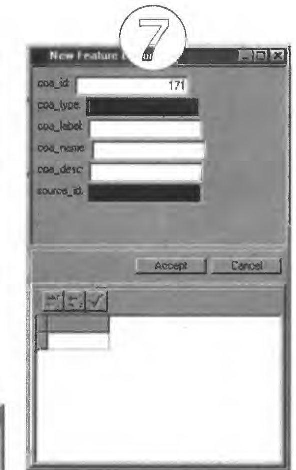
APPENDIX

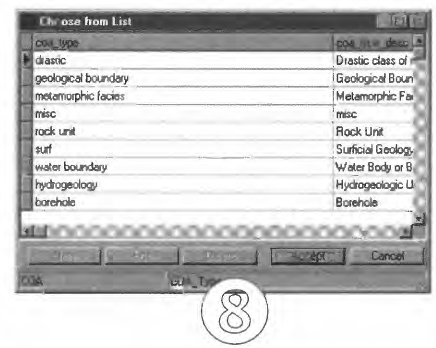
(See captions on page 95.)

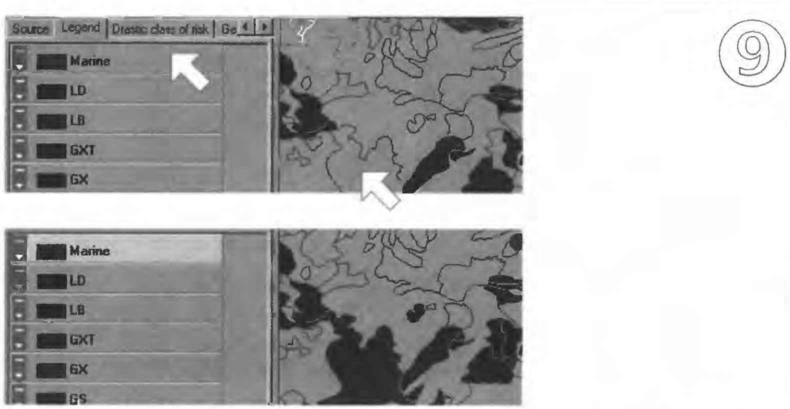












Assigning a spatial object to a classification is as easy as selecting the legend item and clicking on the spatial object!

APPENDIX CAPTIONS

View 1. View of the interface upon connection. One source item has been selected and the map is shown on the right. Data panel on the left displays data entry controls (selected using tabs on the top). Content and number of panels is defined by the database content.

View 2. Data panel showing the legend control (here, surficial geology in French). Canadian shield is selected in the legend control, and the corresponding polygons are shown in dashed pattern. The legend shows a hierarchical structure derived from the COA structure. The till legend item has two siblings (till and rock and till veneer) and is shown in expanded form, whereas others are in contracted form.

View 3. The same maps as in View 2, but till tree is closed. Note that the map is now generalized to this level.

View 4. Data panel shows the data entry panel. The central panel is generated from the structure of the underlying table automatically. The detail table at the bottom is determined from information located in the database, and hence is totally customizable. Light color font shows 'aliasing' in action where a numerical id is replaced by text (also customizable).

View 5. Creating and editing legend items is done visually. The COA tree is listed on the right. Double-clicking on the COA tree opens a COA editor window (view 6).

View 6. COA editor, position in the tree can be altered at will.

View 7. Creating a new entry. This dialog is generated automatically from information in the database. Dark fields announce that these fields will trigger another picklist.

View 8. A linear picklist (as opposed to a tree picklist, shown in view 6). Picklists can be associated with any field in the database.

View 9. Assigning a spatial object to a classification (legend item).

Using Visual Basic to Enhance ArcInfo GRID

By Chip Hankley

Wisconsin Geological and Natural History Survey
3817 Mineral Point Road
Madison, Wisconsin 53705-5100
Telephone: (608) 262-2320
Fax: (608) 262-8086
e-mail: dwhankley@facstaff.wisc.edu

ABSTRACT

Although the GRID module of ArcInfo provides a flexible modeling environment, some operations or conditions may cause extraordinarily slow GRID calculations. The multi-dimensional array capabilities of Visual Basic (VB) and Visual Basic for Applications (VBA) can mimic the raster environment of GRID, and perform spatial operations much faster. This paper demonstrates some of the performance differences between GRID and VB as well as simple techniques for transferring GRID data between ArcInfo and VB/VBA.

INTRODUCTION

The raster-based geographic information system, ArcInfo GRID, provides a powerful framework for model development. As models become more complex, however, GRIDís execution times may become unacceptably long. When this happens, executing the most time-consuming spatial operations outside GRID may provide better results. Any computer programming language that implements multi-dimensional arrays can reproduce the spatial analysis performed in GRID ñ examples include, but are not limited to, C, C++, and Visual Basic (VB).

WHY VISUAL BASIC AND VISUAL BASIC FOR APPLICATIONS?

Visual Basic, as opposed to C or C++, is relatively easy to learn. It represents the evolution of the BASIC language that was first introduced in 1963 (Craig and Webb, 1997). Visual Basic for Applications (VBA) represents a specific implementation of VB.

Visual Basic for Applications comes bundled with many new software packages; it essentially provides an environment for software customization using the VB language. For example, to customize Microsoft Excel, you would write a series of VB commands in the VBA editor. The main differences between VB and VBA are:

- You cannot build an executable program for distribution with VBA.
- An application written in VBA would typically have references in it to some specific component of the software in which the application is embedded. For example, an Excel VBA application would most likely refer to the worksheet names of the workbook, and thus would be meaningless if not directly attached to that Excel workbook.

Many commands work in VBA and VB, so a piece of code that you write to work in a VBA module embedded in an application will, in many cases, work in a stand-alone VB program. For example, you might develop some code using Excel to leverage the power of a spreadsheet for viewing intermediate data output; you would strip out the spreadsheet references upon completion and copy the code into VB for the final product.

The choice of whether to use VBA or VB depends on the overall needs of the application. The commands and methods that this paper covers work in both environments (except where noted). For the remainder of the paper, I will only refer to VB, assuming the reader understands that for the techniques discussed, the two terms are interchangeable.

VISUAL BASIC ARRAYS

An array is "an ordered collection of data contained in a variable and referenced by a single variable name. Each element of the array can be referenced by a numerical subscript" (MSDN, 1998). In VB, arrays are referred to by their name, followed by a numerical reference in parentheses. The following code demonstrates how to create an array called Apple:

```
Dim Apple(4) As String   'Declare
  an Array called Apple
`The array will have 4 elements
`The 4 elements will be of the
  String data type
Apple(0) = "core"
Apple(1) = "skin"
Apple(2) = "pulp"
Apple(3) = "stems"
```

If I refer to `Apple(2)` later in the code, VB will return the string "pulp." Note that by default, VB numbers arrays using a base 0 format; this means that the first element in the array is numbered 0. This can be changed to base 1 by inserting the Option Base 1 statement in the general declarations section of your form or module. For the remainder of this paper, I will refer to arrays as base 1.

The previous example demonstrated a one-dimensional array; that is, the list of elements only extends in one direction. Raster data is more appropriately suited to multi-dimensional arrays.

The following code demonstrates how we might incorporate Grid1, shown in Figure 1, into an array called MyArray:

```
Dim MyArray(4, 4) As String

MyArray(1,1) = "Blue"
MyArray(1,2) = "Green"
MyArray(1,3) = "Red"
...etc.
```

In this example, I am referring to location (1, 1) as the upper left corner, with the first array element referencing rows, and the second element referencing columns. If I wanted to incorporate Grid2 into the array, I could add a 3rd dimension:

```
Dim MyArray(4, 4, 2) As String

MyArray(1, 1, 1) = "Blue"
MyArray(1, 2, 1) = "Green"
MyArray(1, 3, 1) = "Red"
...and
MyArray(1, 1, 2) = "N"
MyArray(1, 2, 2) = "W"
MyArray(1, 3, 2) = "E"
...etc.
```

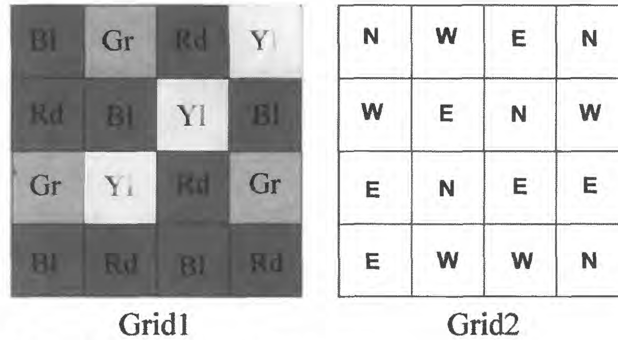


Figure 1. Two hypothetical grids.

Your code will be much more readable if you begin to use variables to refer to different parts of the array:

```
Dim MyArray(4, 4, 2) As String
Dim Grid1 as Integer, Grid2 as
  Integer

Grid1 = 1
Grid2 = 2

MyArray(1, 1, Grid1) = "Blue"
...and
MyArray(1, 1, Grid2) = "N"
...etc.
```

MIMICKING GRID FUNCTIONS

The following GRID statement returns a value of '1' if the cell in Grid1 has a value of 'Red' and the cell in Grid2 has a value of 'N':

```
Grid3 = con(Grid1 eq "Red" AND
Grid2 eq "N", 1, 0)
```

The following VB code would yield the same results:

```
Dim MyArray(4, 4, 3) As String
Dim Grid1 As Integer, Grid2 As
  Integer, Grid3 As Integer
Dim x As Integer, y As Integer

Grid1 = 1
Grid2 = 2
Grid3 = 3

<...code to populate the array
with values for Grid1 and Grid2>
```

```
For x = 1 To 4
   For y = 1 To 4
      If MyArray(x, y, Grid1) =
        "Red" And
              MyArray(x, y, Grid2)
              = "N" Then
              MyArray(x, y, Grid3)
              = "1"
      Else: MyArray(x, y, Grid3) =
        "0"
      End If
   Next y
Next x
```

In all these examples, I am using string values to reflect the values of grid cells. Data that you import from ArcInfo will be numeric; therefore, the arrays that you declare will be of some numeric type. Visual Basic supports a variety of numeric types, including integer, long integer and single and double precision. Each data type takes up a different amount of memory. It is beyond the scope of this paper to delve into memory management in VB; however, this is an area in which to exercise some caution. If you were to import a 10 x 10 integer grid into an array and declare its type as double, the arrayís size would be 4 times larger than if you had declared its type as integer. Failure to effectively manage variable memory can quickly lead to 'out of memory' errors.

DATA EXCHANGE BETWEEN GRID AND VB

Importing data into VB from an ArcInfo raster data set involves VB code that reads the ASCII file created by the ArcInfo GRIDASCII command. Subsequently, returning data from VB to the ArcInfo environment entails VB code that writes the data from a VB array into an ASCII file of the format that the ASCIIGRID command can accept.

Below, I describe the process of importing a 4-cell by 4-cell raster dataset called Grid1 into VB. At each point in the process, I will explain the VB commands and functions that are being used.

STEP 1. Export GRID Data to an ASCII File

From GRID, issue the following command,

```
grid1.grd = GRIDASCII(Grid1)
```

This will generate a file that looks something like this:

```
ncols            4
nrows            4
xllcorner        652029.9375
yllcorner        391156.78125
cellsize         50
NODATA_value     -9999
45   55   67   78
23   3   45  6
66   8   99   12
25   37   105   44
```

STEP 2. Import Data from the ASCII File into a VB Array

In VB, begin entering code in the Form_load procedure. In VBA, you would enter code into a module.

2a) Create a variable that will return the executable fileís path by using the path property.

```
Dim path As String
path = App.path & "\"
```

This is one area in which VB and VBA differ. The App object does not exist in some VBA environments. In Excel you would use the *ActiveWorkbook* object instead. Note that in either case, you should save your work first, so that the path property returns a path other than the default system path.

2b) Create a *FileSystemObject* object that will allow you to open a text file. A *FileSystemObject* is a VB object that allows many types of interactions with ASCII files. Use the *OpenTextFile* method to open the grid1.grd text file.

```
Dim f1 As Variant, in_file As
  Variant
Set f1 = CreateObject
  ("Scripting.FileSystemObject")
Set in_file = f1.openTextFile
  (path + "grid1.grd")
```

2c) Create variables of the appropriate type for the six header fields. Use the *readline* method, combined with the mid function to return the portion of each header line that is a data (not label) element. The *readline* method 'reads an entire line (up to, but not including, the newline character) from a TextStream file and returns the resulting string' (MSDN, 1999). The TextStream file is the file you opened with the *openTextFile* method. Each time the *readline* method is used, VB automatically advances to the next line in the file. The *mid* function allows you to return characters from a string starting at a specific point. Note the line below that begins with "width." This refers to the header line "ncols 4"; position 6 is the first position past the label (ncols). In this case, the *mid* function will return the number 6. Finally, use the *Cint* (change to Integer) or CSng (Change to Single) function to convert the text string that is returned into the appropriate variable type.

```
Dim width As Integer, height As
      Integer, xll As Single, yll
      As Single
Dim CellSize As Single, NoDataSym
      As Single

width = CInt(Mid(in_file.read
      line, 6))
height = CInt(Mid(in_file.readl
      ine, 6))
xll = CSng(Mid(in_file.readline,
      10))
yll = CSng(Mid(in_file.readline, 10))
CellSize = CSng(Mid(in_file.read
      line, 9))
NoDataSym = CSng(Mid(in_file.
      readline, 13))
```

2d) Declare a dynamic array (a dynamic array is an array that you declare without any dimensions) by using the *Dim* statement followed by an array name with empty parentheses after it. Re-dimension its properties to those of the input grid using the *ReDim* statement. Using dynamic arrays is useful when your array sizes have the possibility of changing between program instances.

```
Dim Grid1() As Integer
ReDim Grid1(width, height) As
      Integer
```

2e) Create two string variables (to represent the x and y directions on the grid) and a dynamic string array. Nest two *For...Next* loops, the outer one to count each row and the inner one to count each column. At the beginning of the outer loop, use the *readline* method in conjunction with the *split* function to populate the dynamic string array you just declared. The split function "returns a zero-based, one-dimensional array containing a specified number of substrings" (MSDN, 1998). You must specify what delimits the values in the string returned by *readline* and how many values you want to return; a -1 indicates that all substrings are returned (MSDN, 1999). Inside the inner loop, iteratively assign the individual elements of the string array to the dynamic array you created in the previous step (Grid1()).

```
Dim x As Integer, y As Integer
Dim line1() As String
For y = 1 To height
  line1 = Split(in_file.readline,
      " ", -1)
  For x = 1 To width
    Grid1(x, y) = line1(x - 1)
  Next x
Next y
```

STEP 3 Returning Data from VB to ArcInfo

Getting data out of VB and into ArcInfo basically entails reversing the above process.

3a) Use the *CreateTextFile* method to create a new text file (in this case called junk.grd).

```
' ——— out_fileput to test file
Dim out_file As Variant
Set out_file = f1.CreateTextFile
  (path + "junk.grd", True)
```

3b) Use the *WriteLine* method to write out the six lines of standard GRID header information. *WriteLine*, as the name suggests, simply writes a line of text. Each time the command is issued, VB automatically starts at the next line in the file.

```
out_file.WriteLine ("ncols " +
      CStr(width))
out_file.WriteLine ("nrows " +
      CStr(height))
out_file.WriteLine ("xllcorner " +
      CStr(xll))
out_file.WriteLine ("yllcorner " +
      CStr(yll))
out_file.WriteLine ("cellsize " +
      CStr(CellSize))
out_file.WriteLine ("NODATA_value "
      + CStr(NoDataSym))
```

3c) Declare a one-dimensional array with the width of your grid as its number of elements. As before, nest two *For...Next* loops, one for rows and one for columns. In the inner loop, add data from your array to the one-dimensional array you just created. At the end of the outer loop, use the *Join* function to join all elements of the one-dimensional array into one text stream. If no delimiter is specified when using the *Join* function, a space is used (MSDN, 1999).

```
Dim line_o() as String
ReDim line_o(width)
For y = 1 To height
  For x = 1 To width
    line_o(x) = Grid1(x, y)
  Next x
  out_file.WriteLine (Join(line_o))
Next y
```

3d) Finally, close the text file.

```
out_file.Close
```

At this point, you have imported the ASCII file grid1.grd, read the file into a VB array, then written it out to an ASCII file called junk.grd. Presumably, between steps 2 and 3, you would write VB code to perform your spatial analysis, which would result in the array that you would write out in step 3.

VISUAL BASIC VS. GRID: COMPARING PERFORMANCE

I developed a routine that could easily be written either solely in Arc Macro Language (AML), or using a combination of AML and VB. The routine iteratively routes the cell values of an initial grid over a surface, applying a simple function to the values as they move from cell to cell (this would be similar to routing water over a topographic surface using a runoff coefficient to determine how much water passes from one cell to the next). The routine uses a spiraling flow-path that terminates in the center of the grid (figure 2). This simulates an extreme routing scenario. For the value in the upper left hand cell to reach the center, it must pass through every cell in the grid. Although this routing scenario would rarely be encountered in a real application, it provides a good scenario for comparing VB and GRID.

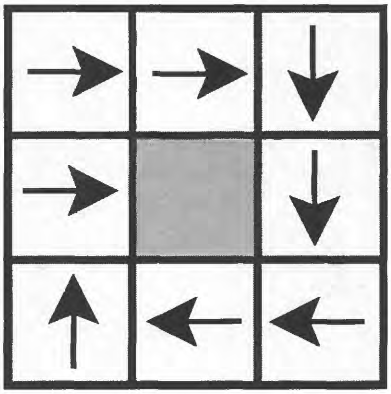


Figure 2. A 3 x 3 grid with spiraling flowpath that terminates in the center.

To compare performance, I wrote separate AMLs. The first AML utilizes DOCELL loops to accomplish the iterative routing; the second AML begins by exporting the input grids to ASCII files and then calls a VB executable that performs the routing using arrays and writes out a GRID compatible ASCII file. The final portion of this second AML imports the output grid. Appendix 1 contains the AML-only version; Appendix 2 contains the combined AML - VB version.

I created input grids of various sizes and ran the two AMLs against each of the input grids. Table 1 and figure 3 show each AML's program execution time for each grid used. Execution times were generated using ArcInfo's performance timer, which records time in one-second intervals. Some of the program execution times were too short to be accurately reflected by a one-second interval; to account for this, figure 3 shows a 0.5 second error associated with each point.

Table 1 portrays program execution time in two different ways (T1 and T2). T1 simply reflects the time it took for the program to execute; T2 attempts to look at the most time consuming process in the sample routine — the iterative routing. T2 is shown as a range to account for any uncertainty associated with the one-second time interval, and was calculated by dividing (T1 + 0.5) by the number of cells in the input grid, and the number of iterative loops.

T2 represents an attempt to quantify how long it takes for the processor to analyze one cell in the input grid. For this routine, there are many program operations that could be considered overhead. Some of these might take the same amount of time regardless of the input grid size (for example, calls to the system clock), while others may vary with input grid size (for example, ASCIIGRID and GRIDASCII commands). At some point in the programís execution, however, the processor must begin the onerous task of analyzing each cell in the input grid, moving values from cell to cell — looping through this process until all of the values have been routed to the center. As mentioned above, the routine was set up so that the number of times the program would have to loop through this iterative process would be equal to the number of cells in the input grid. As the size of the input grid increases, the effect of the overhead processes on the overall program execution time should decrease (indicated by T2 reaching a steady state), and you should be able to compare single cell processing time between VB and GRID. Figure 4 shows that T2 seems to level off at about 0.5 milliseconds for GRID, and about 0.001 milliseconds for VB.

On the basis of these results, it is clear that, at least for this particular type of analysis, VB far outperforms GRID: for the same numerical operation, VB may perform up to 500 times faster than GRID.

These tests were run on an Omni-Tech desktop PC, with a Pentium III 500 MHz processor and 256 MB RAM. ArcInfo 8.0.1 and Visual Basic 6.0 were used to complete the analysis.

CONCLUSIONS

Although it is impossible to make a sweeping comparison between the two, Table 1 and Figures 3 and 4 show that VB is much faster than GRID for the conditions tested. However, there are most likely circumstances in which GRID would outperform VB. All analyses have unique circumstances; thus the decision to use VB over GRID will rely on weighing a variety of pros and cons. Probably the most important factor to consider is the increased overhead

Table 1. AML only (GRID) and combined AML / VB (VB) performance times for the test routine. T1 is the total program execution time in seconds; T2 is an estimate of the cell processing time (expressed as a range) in milliseconds for the iterative phase. Where VB returned a value of 0 for T1, a time of 0.01 seconds was used in order to facilitate calculations.

Input Grid Size	Number of Iterative Loops	GRID		VB	
		T1	T2	T1	T2
2x2	4	3	156.25 - 218.75	0.01	0.63 - 31.25
4x4	16	11	41.02 - 44.92	1	1.95 - 5.86
6x6	36	26	19.68 - 20.45	0.01	0.01 - 0.39
8x8	64	44	10.62 - 10.86	0.01	2.44E-03 - 0.12
10x10	100	69	6.85 - 6.95	0.01	1.00E-03 - 5.00-02
15x15	225	159	3.13 - 3.15	1	9.88E-03 - 2.96E-02
20x20	400	293	1.83 - 1.83	1	3.13E-03 - 9.38E-03
30x30	900	720	0.89 - 0.89	1	6.17E-04 - 1.85E-03
40x40	1600	1464	0.57 - 0.57	3	9.77E-04 - 1.37E-03
60x60	3600	4269	0.33 - 0.33	17	1.27E-03 - 1.35E-03
80x80	6400	16198	0.40 - 0.40	50	1.21E-03 - 1.23E-03
100x100	10000			119	1.19E-03 - 1.20E-03
150x150	22500			678	1.34E-03 - 1.34E-03

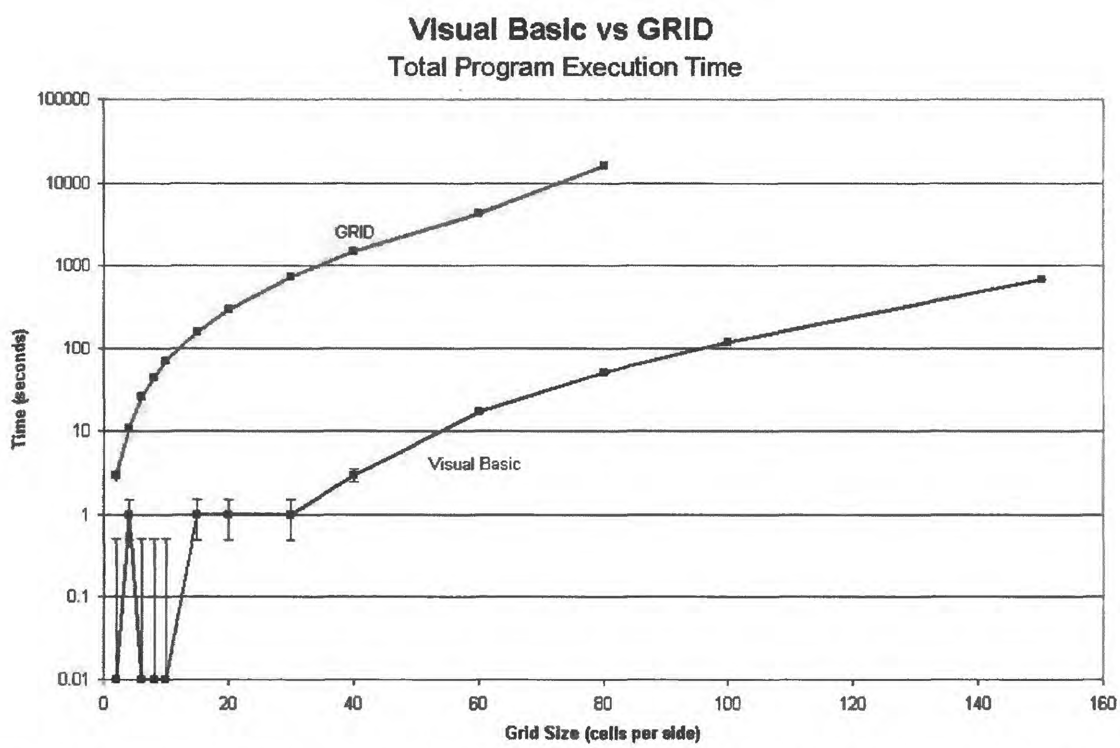


Figure 3. GRID and VB performance (Table 1, T1) for a variety of input grid sizes. The error bars show a + 0.5 second confidence.

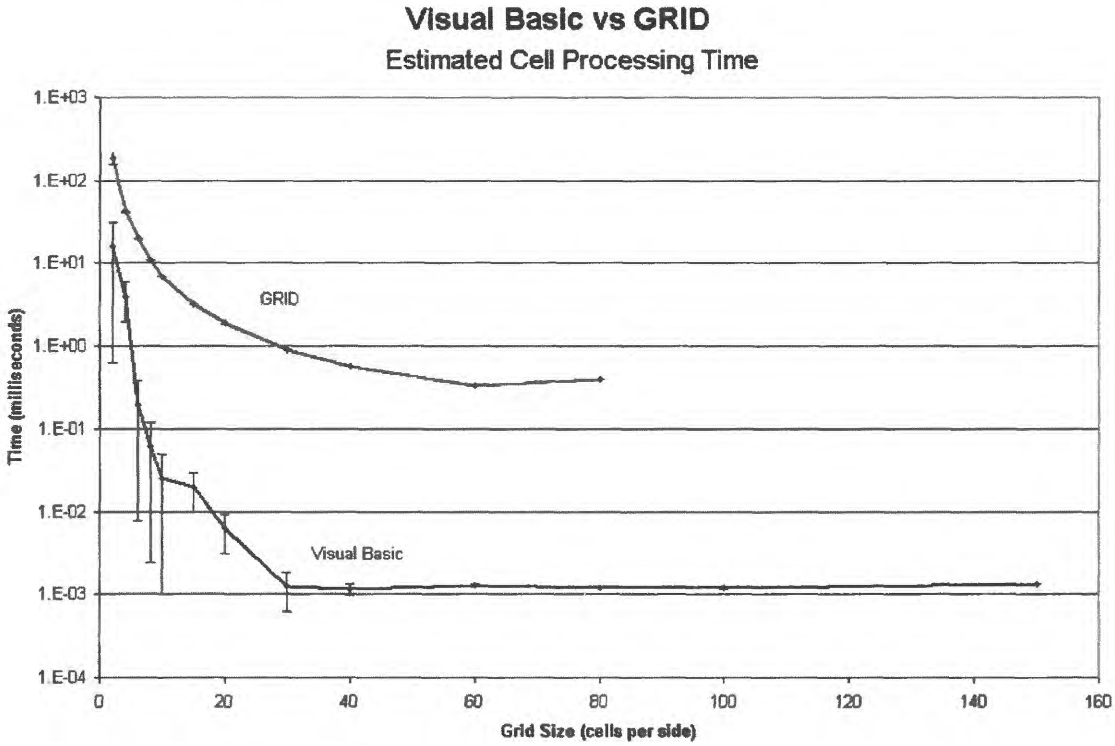


Figure 4. Plot of the mean of the T2 range for each input grid size. The error bars indicate the upper and lower bounds of the range.

involved in implementing a spatial project in VB over GRID (data must be imported and exported, spatial functions must be defined)—essentially you would consider if the time savings you will see by converting to VB will offset the increased development time.

In those cases in which it makes sense to do spatial analyses outside of the GRID environment, VB's ease of programming its speed make it a powerful tool for the GRID modeler.

REFERENCES

Craig, John C., and Webb, Jeff, 1997, Microsoft Visual Basic 5.0, Developer's Workshop (Fourth Edition): Microsoft Press, Redmond, WA.

MSDN Library, Visual Studio 6.0, 1998 [Computer Program], available from: Microsoft Corporation, Redmond, WA.

APPENDIX 1

```
/*——————————————
/* AML_DEMO.aml
/*
/*This is a routing simulation program used to provide a testing
/*benchmark between Visual Basic and ArcInfo GRID. This version
/*uses only AML.
/*
/*REQUIRED INPUTS
/*
/*FL_DIR: a directional grid of the type created by the GRID
/*command
/*FLOWDIRECTION. Direction should be such that all cells in the
/*grid flow into and terminate at one interior cell
/*
/*RO_COEFF: a grid of values greater than or equal to 1.
/*
/*RESULTS.DAT an empty or existing text file
/*
/*THIS PROGRAM MUST BE RUN FROM GRID
/*——————————-  Program Setup
&severity &error &routine bailout
&messages &off
verify off

/*——————————-  Cleanup any Pre-existing files
&if [EXISTS t_w.grd -file] &then &sys del t_w.grd
&if [EXISTS cum_max.dat -file] &then &sys del cum_max.dat
&if [EXISTS t_w -grid] &then kill t_w all
&if [EXISTS water -grid] &then kill water all
&if [EXISTS roin -grid] &then kill roin all
&if [EXISTS fl_dir.grd -file] &then &sys del fl_dir.grd
&if [EXISTS ro_coeff.grd -file] &then &sys del ro_coeff.grd

/*——————————-  Set initial Time variable
&sv time_beg = [show &pt time]

/*—————- Create an initial grid of values to be routed
setwindow fl_dir
setcell fl_dir
water = 2 * ro_coeff
t_w = water /*Total Water Grid

/*——————————-  Set some variables
&describe water
&sv mn = %grd$mean%
&sv cum_max = 0
&sv count = 0

/*——————————-  ROUTE the values in the water grid until
/*                          there is no water left (i.e. until it has
/*                          all flowed into the terminal cell

&do &until %mn% lt 0.000001
```

```
  DOCELL
   outval = scalar(0.0)
   sum = scalar(0.0)
   if (fl_dir(1,0) == 16) outval += water(1,0)
   if (fl_dir(1,1) == 32) outval += water(1,1)
   if (fl_dir(0,1) == 64) outval += water(0,1)
   if (fl_dir(-1,1) == 128) outval += water(-1,1)
   if (fl_dir(-1,0) == 1) outval += water(-1,0)
   if (fl_dir(-1,-1) == 2) outval += water(-1,-1)
   if (fl_dir(0,-1) == 4) outval += water(0,-1)
   if (fl_dir(1,-1) == 8) outval += water(1,-1)
   else outval += 0
   ROin = float(outval)
  END

  water = float(ROin)
  t_w = t_w + water
  &describe t_w
  &if %cum_max% lt %grd$zmax% &then
    &sv cum_max = %grd$zmax%
  &describe water
  &sv mn = %grd$mean%
  water = water * ro_coeff
  &sv count = %count% + 1

&end

/*---------- Set Final Time variable
&sv time_end = [show &pt time]

/*---------- The following lines will write out the
/*                    results of this run to a text file called
/*                    results.dat. The results written will be
/*                    1) Input Grid Size 2) Program execution
/*                    time,
/*                    3)Number of loops, and 4) Amount of 'water'
/*                    routed to the terminal cell
&describe fl_dir
&sv string = [QUOTE AML SIZE: %grd$ncols% TIME: %time_end% LOOPS: %count% AMT:
%cum_max%]

&sv open_file = [OPEN results.dat Openstat -APPEND]
&if [WRITE %open_file% %string%] <> 0 &then
  &do
    &type Unable to write to file
    &sv close_stat = [CLOSE %open_file%]
    &call exit
  &end
&sv close_stat = [CLOSE %open_file%]

/*---------- Type the results to the screen
&type AML records that the total water collected is %cum_max%
&type    This AML did %count% loops
&type    Elapsed Program Time: %time_end% seconds
kill (!t_w water roin!) all
```

```
&call exit
&return
/*******************************************
/*EXIT
&routine exit
&watch &off
&echo &off
&messages &on
&return
/* Perform Cleanup actions if Program Fails
&routine bailout
&severity &error &fail
&call exit
&return &error Bailing out of RO.aml
```

APPENDIX 2

There are two parts to the combined AML — VB simulation: the AML, and the VB executable that it calls.

AML portion

```
/*——————————
/* VB_DEMO.aml
/*
/*This is a routing simulation program used to provide a testing
/*benchmark between Visual Basic and ArcInfo GRID. This version
/*utilizes a combination of VB and AML.
/*
/*REQUIRED INPUTS
/*
/*FL_DIR: a directional grid of the type created by the
/*GRID command
/*FLOWDIRECTION. Direction should be such that all cells
/*in the grid flow into and terminate at one interior cell
/*
/*RO_COEFF: a grid of values greater than or equal to 1.
/*
/*RESULTS.DAT an empty or existing text file
/*
/*THIS PROGRAM MUST BE RUN FROM GRID
/*——————-  Program Setup
&severity &error &routine bailout
&messages &off
verify off

/*——————-  Cleanup any Pre-existing files
&if [EXISTS t_w.grd -file] &then &sys del t_w.grd
&if [EXISTS cum_max.dat -file] &then &sys del cum_max.dat
&if [EXISTS t_w -grid] &then kill t_w all
&if [EXISTS water -grid] &then kill water all
&if [EXISTS roin -grid] &then kill roin all
```

```
&if [EXISTS fl_dir.grd -file] &then &sys del fl_dir.grd
&if [EXISTS ro_coeff.grd -file] &then &sys del ro_coeff.grd

/*----------- Set initial Time variable
&sv time_beg = [show &pt time]

/*----------- Write the input grids to ASCII files
ro_coeff.grd = gridascii(ro_coeff)
fl_dir.grd = gridascii(fl_dir)
/*----------- Execute the VB program
&sys vbdocell.exe

/*----------- Import the TOTAL WATER grid
t_w = asciigrid(t_w.grd, float)

/*----------- Read the cum_max  and count variables
/*                     from the cum_max.dat text file
&sv open_file = [OPEN cum_max.dat Openstat -READ]
&sv cum_max = [READ %open_file% Readstat]
&sv count = [READ %open_file% Readstat]
&sv close_stat = [CLOSE %open_file%]

/*----------- Set Final Time variable
&sv time_end = [show &pt time]

/*----------- The following lines will write out the
/*                     results of this run to a text file called
/*                     results.dat. The results written will be
/*                     1) Input Grid Size 2) Program execution
/*                     time,
/*                     3)Number of loops, and 4) Amount of 'water'
/*                     routed to the terminal cell
&describe fl_dir
&sv string = [QUOTE VB SIZE: %grd$ncols% TIME: %time_end% LOOPS: %count% AMT:
%cum_max%]

&sv open_file = [OPEN results.dat Openstat -APPEND]
&if [WRITE %open_file% %string%] <> 0 &then
  &do
    &type Unable to write to file
    &sv close_stat = [CLOSE %open_file%]
    &call exit
  &end
&sv close_stat = [CLOSE %open_file%]

/*----------- Type the results to the screen
&type VB records that the total water collected is %cum_max%
&type    Elapsed Program Time: %time_end% seconds
&type    The VB Script did %count% loops

&call exit
&return
/*******************************************
/*EXIT
&routine exit
&watch &off
```

```
&echo &off
&messages &on
&return
/* Perform Cleanup actions if Program Fails
&routine bailout
&severity &error &fail
&call exit
&return &error Bailing out of RO.aml
```

VB Executable

You should copy this code directly into a form's code window.

```
Option Explicit 'Force Explicit declaration of variables
Option Base 1   'Force Base 1 arrays
Private Sub Form_Load()
'————————————————————————
' VB_DOCELL
'
' This is a routing simulation program used to provide a testing
' benchmark between Visual Basic and ArcInfo GRID. This VB program
' will be called from the vb_demo AML.
'
' This program demonstrates how to read in ASCII grid datasets,
' how to perform spatial operations within the VB environment, how
' to pass variables back into AML, and how to write VB arrays out
' to an ASCII format that GRID can read.
'
' REQUIRED INPUTS
'
' FL_DIR: an ASCII version of a directional grid of the type
' created by the GRID command FLOWDIRECTION. Direction should be
' such that all cells in the grid flow into and terminate at one
' interior cell.
'
' RO_COEFF: an ASCII grid of values greater than or equal to 1.
'
'—————————- Set the path for the application
Dim path As String
path = App.path & "\"
'Use the next line if working in EXCEL, comment out the previous
' one.
'path = ActiveWorkbook.path & "\"
'—————————- Open up the fl_dir and ro_coeff ascii grids
'                        and read them into an array
Dim f1 As Variant, fl_dir_file As Variant, ro_coeff_file As Variant
Set f1 = CreateObject("Scripting.FileSystemObject")
Set fl_dir_file = f1.openTextFile(path + "fl_dir.grd")
Set ro_coeff_file = f1.openTextFile(path + "ro_coeff.grd")
'—————————- Read the header information for the grids
Dim width As Integer, height As Integer, xll As Single, yll As
       Single
Dim CellSize As Single, NoDataSym As Single, c As Integer
'The following 6 lines read information from the header rows
```

```
width = CInt(Mid(fl_dir_file.readline, 6
height = CInt(Mid(fl_dir_file.readline, 6))
xll = CSng(Mid(fl_dir_file.readline, 10))
yll = CSng(Mid(fl_dir_file.readline, 10))
CellSize = CSng(Mid(fl_dir_file.readline, 9))
NoDataSym = CSng(Mid(fl_dir_file.readline, 13))

'Skip the first 6 lines on the ro_coeff_file so that
'readline is pointing to the same location for both
For c = 1 To 6
      ro_coeff_file.readline
Next c
'————— Read in the flow direction and ro_coeff data
' from the ASCII files
Dim FL_DIR() As Integer, ro() As Double, line1() As String
Dim line2() As String, water As Integer, ro_in As Integer
Dim t_w As Integer, RO_COEFF As Integer, x As Integer, y As
       Integer

ReDim FL_DIR(width, height) As Integer
ReDim ro(width, height, 4) As Double

water = 1
ro_in = 2
t_w = 3
RO_COEFF = 4

For y = 1 To height
line1 = Split(fl_dir_file.readline, " ", -1)    'flow direction
line2 = Split(ro_coeff_file.readline, " ", -1) 'ro_coeff
      For x = 1 To width
            FL_DIR(x, y) = line1(x - 1)
                  ro(x, y, RO_COEFF) = line2(x - 1)
      Next x
Next y
'Close the input files
fl_dir_file.Close
ro_coeff_file.Close

'————— Populate the ro_array with an initial value
For y = 1 To height
      For x = 1 To width
            ro(x, y, water) = 2 * ro(x, y, RO_COEFF)
            ro(x, y, t_w) = ro(x, y, water)
      Next x
Next y
'————— Begin routing the water
Dim sum As Double, cum_max As Double, Count As Integer

Count = 0
cum_max = 0
sum = 1
Do While sum > 0
      For y = 1 To height
            For x = 1 To width
                  If FL_DIR(x, y) = 1 And x <> width Then
```

```
                    ro(x + 1, y, ro_in) = ro(x + 1, y, ro_in) +
                     ro(x, y, water)
                End If
                If FL_DIR(x, y) = 2 And x <> width And y <> height Then
                    ro(x + 1, y + 1, ro_in) = ro(x + 1, y + 1,
                     ro_in) + ro(x, y, water)
                End If
                If FL_DIR(x, y) = 4 And y <> height Then
                    ro(x, y + 1, ro_in) = ro(x, y + 1, ro_in) +
                     ro(x, y, water)
                End If
                If FL_DIR(x, y) = 8 And x <> 1 And y <> height Then
                    ro(x - 1, y + 1, ro_in) = ro(x - 1, y + 1,
                     ro_in) + ro(x, y, water)
                End If
                If FL_DIR(x, y) = 16 And x <> 1 Then
                    ro(x - 1, y, ro_in) = ro(x - 1, y, ro_in) +
                     ro(x, y, water)
                End If
                If FL_DIR(x, y) = 32 And x <> 1 And y <> 1 Then
                    ro(x - 1, y - 1, ro_in) = ro(x - 1, y - 1,
                     ro_in) + ro(x, y, water)
                End If
                If FL_DIR(x, y) = 64 And y <> 1 Then
                    ro(x, y - 1, ro_in) = ro(x, y - 1, ro_in) +
                     ro(x, y, water)
                End If
                If FL_DIR(x, y) = 128 And x <> width And y <> 1 Then
                    ro(x + 1, y - 1, ro_in) = ro(x + 1, y - 1,
                     ro_in) + ro(x, y, water)
                End If
            Next x
        Next y
        sum = 0
        'Prepare for the next loop:
        For y = 1 To height
            For x = 1 To width
                ro(x, y, water) = ro(x, y, ro_in)
                ro(x, y, t_w) = ro(x, y, t_w) + ro(x, y, water)
                If cum_max < ro(x, y, t_w) Then
                    cum_max = ro(x, y, t_w)
                End If
                sum = sum + ro(x, y, water)
                ro(x, y, water) = ro(x, y, water) * ro(x, y,
                 RO_COEFF)
                ro(x, y, ro_in) = 0
            Next x
        Next y
        sum = sum / (width * height)
        Count = Count + 1
Loop

'---------- Output the matrix to t_w ascii file
Dim out_file As Variant
Set out_file = f1.CreateTextFile(path + "t_w.grd", True)
out_file.WriteLine ("ncols " + CStr(width))
```

```
out_file.WriteLine ("nrows " + CStr(height))
out_file.WriteLine ("xllcorner " + CStr(xll))
out_file.WriteLine ("yllcorner " + CStr(yll))
out_file.WriteLine ("cellsize " + CStr(CellSize))
out_file.WriteLine ("NODATA_value " + CStr(NoDataSym))

Dim line_o() As String
ReDim line_o(width)
For y = 1 To height
      For x = 1 To width
            line_o(x) = ro(x, y, t_w)
      Next x
      out_file.WriteLine (Join(line_o))
Next y
out_file.Close

'---------- Output cum_max and count to a text file
Set out_file = f1.CreateTextFile(path + "cum_max.dat", True)
out_file.WriteLine (cum_max)
out_file.WriteLine (Count)
out_file.Close

'---------- Release object variables
Set out_file = Nothing
Set fl_dir_file = Nothing
Set ro_coeff_file = Nothing
Set f1 = Nothing


End 'End the routine before form_load completes

End Sub
```

Geological Map Production for Dummies

By Vic Dohar and Dave Everett

Natural Resources Canada
601 Booth Street
Ottawa, Ontario
K1A 0E8
Telephone: (613) 943-2693, 996-9353
Fax: (613) 952-7308
e-mail: vdohar@nrcan.gc.ca, devertt@nrcan.gc.ca

INTRODUCTION

The Cartographic Services Section of the Earth Sciences Info Division, Natural Resources Canada produces maps for the geologists of the Geological Survey of Canada (GSC). The section consists of 30 employees, 20 being cartographers, along with cartographers in regional GSC offices across the country. Approximately 60-80 geological maps are published per year, with the majority being plotted by an on-demand system. A variety of products are produced, including A-series, open files and various posters for the general public and educational clients.

In late 1999, the section became ISO 9001 registered (International Standards Organization), committing the section to producing quality products and providing quality services that satisfy or exceed client requirements. This has involved developing a production and management system resulting in high quality and timely delivery of cartographic products. The system itself is comprised of procedures, production guidelines, forms and instruction manuals. Scheduled audits of the section are required in order to maintain ISO 9001 registration status.

History of Digital Production

The section began experimenting with ESRI's ArcInfo software in the late 1980's, using version 5.0 on a VAX/VMS platform/operating system. By 1992, our first digital map was produced and by 1994, after training of staff of the new digital technology, all geological maps were being produced using ArcInfo 6.0 on Sun UNIX workstations. In 1995, the section's on-demand system was established to quickly publish open files. More recently, the use of ArcInfo software has been shifting from a UNIX to a Windows NT operating environment.

PRODUCTION STEPS

The cartographic production steps are generally divided into the following six steps:

1) Acquisition and Input

Digital data is usually obtained from the geologist as a DXF or E00 file from Fieldlog, AutoCAD, or MiniCAD. Point data can also be accepted as an ASCII file. Original mylar or paper manuscripts are scanned and vectorized using ArcInfo.

2) Verification

Things we always ask ourselves and the geologist before starting any edits...

- Is the data in the correct projection and datum as stated by the geologist?
- Is the data accurately geo-referenced?
- Is the latest available digital base used?
- Is the data properly feature coded?
- Is all supporting documentation supplied by the geologist?

3) Editing and Attributing

Main tasks involve ensuring features are topologically correct, attributed and symbolized according to Cartographic Digital Standards (CDS). Original manuscripts that were scanned require geo-referencing, and interactive editing and feature coding. All text or annotation on the map is added interactively.

4) Preparing the Map Layout

Most surround information is plotted as separate custom ArcInfo plotting commands relying on meta data information (e.g., commands would be TITLEBLOCK, CITATION, and GSCLOGO). Geological legends are created using a simple text or ASCII file, and descriptive notes, references and figures are included as EPS files.

5) Quality Control

A filtering process is used to create a report document that checks the project for completeness and correct feature attribution. Quality control officers ensure that the map meets design specifications and that the digital data conforms to CDS. All maps are reviewed by the geologist prior to publication and A-series maps are further reviewed by scientific editors.

6) Plotting/Printing and Archiving

A final PostScript file is created for both the on-demand plotting system and for offset printing. The project is archived onto two CD-ROM's, including E00 and shape files of all coverages used in the production of the map.

GEOLOGICAL MAPPING SYSTEM (GEMS)

GEMS is simply a graphical user interface and a set of custom ArcInfo plotting commands used to aid cartographers in the production of geological maps. Many repetitive and routine tasks are compiled into programs. It is written entirely in AML (Arc Macro Language), consisting of approximately 800 files. GEMS also includes the standard GSC symbolsets for lines, markers (points), shades (area), and text. Currently, it is compatible with ArcInfo 7.2.1, and testing with ArcInfo 8.0.1 (workstation version) is under way. GEMS can be downloaded free from our web site, <http://nrcan.gc.ca/ess/carto/english/reference/gems/gems.html>, as a 24Mb tar file. Listed below are a few of the GEMS tools that cartographers use every day.

Map Border

A map border can be created simply by specifying the publication scale, latitude and longitude extremes, name of coverage to create, and projection definition (figure 1).

Editing Annotation

GEMS simplifies the adding and editing of annotation in ArcInfo, by an easy to use menu. Users simply have to specify the publication scale, the size of annotation in points not coverage units, the text symbol from the textset, the text string and whether the annotation is placed along an existing arc, at 90 degrees or by entering coordinates with the mouse. Options also exist to automatically adjust angle of annotation to be square with page when specifying a map angle (figure 2).

Map Surround

Surround information on the map, such as logos, location map, titleblock, and recommended citation, are all plotted using custom plotting commands (AML programs) that uses meta data information (figure 3). The custom LEGEND command is used to plot a geological legend by using a simple text or ASCII file. The text file obtained from the geologist is edited and embedded with special legend plotting commands and codes (shown in bold in sample text file below). These commands and codes, in turn, plot boxes, lines, symbology, and text that are common to all geological legends (figure 4).

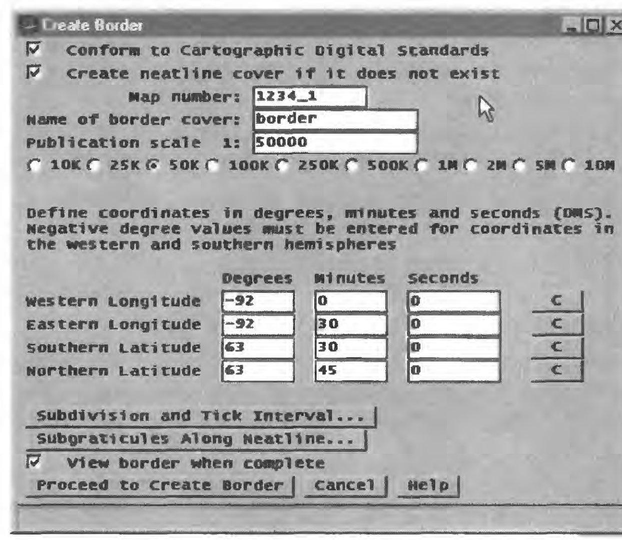


Figure 1. Menu for entering map border specifications.

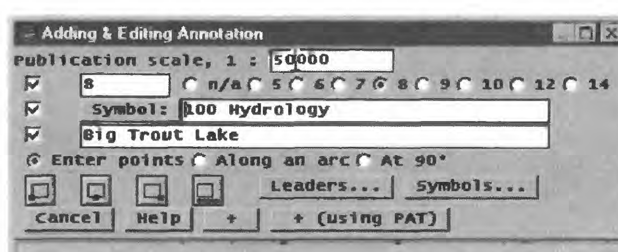


Figure 2. Menu for adding and editing annotation.

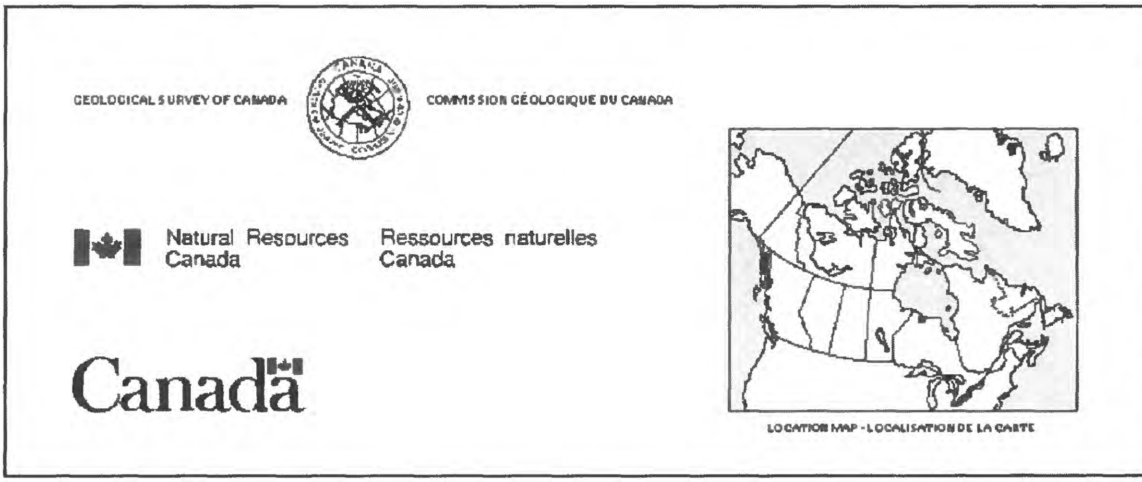


Figure 3. Sample map surround elements.

```
/* Change default settings
SET box_font GSCSpecial-Regular
AP 'SHADEDELETE ALL; SHADESET GSC'
COLUMN 3.0 0.5
BRACKET TOP
HEADING L QUATERNARY
BOX 7 /Mr
DESC
Glacial deposits; gravel and sand

BRACKET BOTTOM CENOZOIC DOWN
BRACKET TOP
TEXT 'INTERMEDIATE STRUCTURAL
 SLICES' DASH
BOX 9 |Mr
DESC
Interlayered rhyolilte, mafic tuff
 and flows, slate

BOX 25
AP 'SHADEDELETE ALL; SHADESET
 GSC_PTRN'
PATTERNFILL 120 # # ON |Mg
AP 'SHADEDELETE ALL; SHADESET GSC'
DESC
Black and green mudstone, greywacke

BOX 116 |Ka # 1
DESC
FRASER BROOK FORMATION: !FNT110001;
 |Ka!FNT110003;, rhyolite, minor
 andesite, basalt, red siltstone,
 slate; !FNT110001;|Kb!FNT110003;,
 andesite, minor rhyolite, basalt,
 red siltstone; !FNT110001;
 |Kc!FNT110003;, basalt,minor
 andesite, rhyolite, slate, minor
 volcanics

BOXSIZE 4.5 10
SUBBOX 9 0 117 b
SUBBOX 13.5 0 119 c
BRACKET BOTTOM PROTEROZOIC UP
END
```

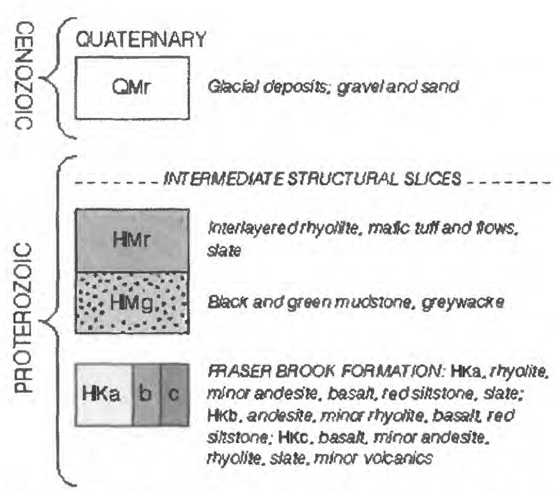


Figure 4. Geological legend created from above sample text file.

Custom GSC Symbolsets and Geological Font

All of the GSC symbolsets are created in ArcInfo using IGL fonts. The symbolsets are continuously being updated as new symbols are added based on requests from the geologists. Symbol numbers in the GSC colour shadeset correspond to percentages of cyan, magenta and yellow (e.g., symbol 264 is 20% cyan, 60% magenta and 40% yellow). GSC symbolsets are included with GEMS or are available separately at the web site.

The special geological font consists of age characters and is required in order to meet our design specifications. These special characters are mapped to non-alpha characters on the keyboard, which still allows the use of alpha characters. In addition, uppercase alpha characters are scaled 80% as per design specifications (figure 5).

CARTOGRAPHIC DIGITAL STANDARDS (CDS)

The Cartographic Digital Standards explains the general procedures for each production phase of a geological map. It lists the required coverages and files for each map project/workspace, along with the naming convention, definitions and content of feature attribute tables. The features are managed by dividing them into the following three categories: base, geology and other.

Base Features consists primarily of hydrology features, comprised of arcs and polygons, where the polygons are used as a water mask when making final plots. In other words, water bodies are plotted as solid white, masking the geology plotted beneath. Remaining base features are divided into two coverages, one for lines and points, and the other for polygons.

Geology features are divided into four coverages: geological units and contacts consisting of arcs and polygons, linear features, point features, and overlapping polygons, consisting of arcs and polygons.

Other features completing the geological map consists of the map border and neatline, all annotations or text on the map, miscellaneous features for the purpose of hardcopy output, and the NTS (National Topographic System) Reference Map.

Symbolizing and Coding Features

In order to symbolize features for hardcopy output, each feature attribute table contains an integer item, where its value corresponds to a symbol from the symbolset file. In addition, each feature attribute table contains an item CODE, where its value relates to a legend INFO file or lookup table. The legend info file contains the description of the feature as it appears in the legend on the hardcopy map.

In addition, geology features have links for relates to other external tables or INFO files as supplied by the geologist. Point features have a few additional items to record common information such as strike and dip values.

OUTPUT

Map output primarily takes the form of a hardcopy map, published either by on-demand plotting or offset printing. Digital release of data is available upon permission from the geologist's division director, and is distributed on CD-ROM. Displaying geological maps on the internet in an interactive format is in the preliminary stages of development.

On-Demand Plotting Service

The on-demand plotting system was initiated in 1995 using high-speed single-pass Synergy electrostatic plotters

510 CQRPTPMOEPNPMKJTPPPMCDSOCPHHNPAA
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz

Usage: Geological References
Font: 110001 GSCSpecial-Regular (PostScript Type I)
Colour: Blackx
Style: TYPESET

Corresponding keyboard characters for GSC Special characters

CENOZOIC C 1
QUATERNARY Q /
RECENT R #
PLEISTOCENE P $
TERTIARY T 2
PLIOCENE P &
MIOCENE M 6
OLIGOCENE O (
EOCENE E)
PALEOCENE P *
NEOGENE N +
PALEOGENE P .
MESOZOIC M :
CRETACEOUS K 3
JURASSIC J <
TRIASSIC T =
PALEOZOIC P >
PERMIAN P ?
PENNSYLVANIAN P @
MISSISSIPPIAN M 4
CARBONIFEROUS C 7
DEVONIAN D 5
SILURIAN S ^
ORDOVICIAN O _
CAMBRIAN C `
PROTEROZOIC P {
HADRYNIAN H |
HELIKIAN H }
NEOHELIKIAN N ~
PALEOHELIKIAN P 8
APHEBIAN A 9
ARCHEAN A 0

Figure 5. Geological age font showing keyboard mapping.

(no longer available). These plotters were able to produce an average size map in about one minute, much faster than today's inkjet technology, however image and paper quality were poor. In an effort to produce high quality press-like maps using an on-demand system, HP ink jet plotters and a ZEH graphics RIP (raster image processing) were implemented in late 1999.

The system is used for plot file submissions by geologists, cartographers, and map sales at the GSC Book Store. A web-based interface is accessible by users with account privileges for submitting plot files and monitoring the plotting queues. Currently, there are four plotters available (36" and 54") for plotting, producing approximately 6000 plots per year. In addition, the ZEH graphics RIP system has been modified to include a method to record plotting usage for cost recovery purposes.

Offset Printing

A-series maps are printed using offset printing where large sales and distributions are forecasted (approximately 500 or more sheets). PostScript files created from ArcInfo are used to create negatives from which a pre-press proof and printing plates are created. Printing and negative artwork generation is performed within the department, as these facilities are used in conjunction with other government mapping agencies.

GIS Data Development of the Geology of the Fort Polk Region of West-Central Louisiana

By R. Hampton Peele and Richard P. McCulloh

Louisiana Geological Survey
Louisiana State University
208 Howe-Russell Geoscience Complex
Baton Rouge, Louisiana 70803-4101
Telephone: (225) 388-5320
Fax: (225) 388-3662
e-mail: Hampton@lsu.edu, mccullo@lsu.edu

ABSTRACT

Ten 7.5-minute quadrangles in west-central Louisiana were the subject of an investigation into the geology of the Fort Polk region for the U.S. Army Corps of Engineers, between 1996 and 1999. The surface geology theme was mapped from field work, in the context of previous work done in the area; the economic geology was mapped, as a derivative layer, from the surface geology; and the geologic hazards theme, found to comprise only flooding, was recompiled from the Federal Emergency Management Agency (FEMA) flood maps. This project included the development of a Geographic Information System (GIS) data layer of the surface geology and derivative themes. For the surface geology, alluvial and nonalluvial (suballuvial) contact boundaries were prepared separately, because they were derived from different types of data: in contrast to the other map units, alluvium was interpreted principally from topographic maps rather than from field work. The alluvial and nonalluvial boundary lines were scanned separately and merged in the GIS to create a composite of surface geology polygons. Small but numerous subsequent problems deriving from this procedure indicated that manually combining the two layers prior to scanning would have been preferable. Faults are treated in the GIS as a separate layer of the surface geology, but set up to be turned on whenever the surface geology is viewed. The economic geology is a mixed representation of polygons and points, and geologic hazards (flood zones) are represented with polygons.

The images of the scanned lines were digitized using the Directional Trace Line String function of INTERGRAPH's GEOVEC software. Each quadrangle of digitized linework was georeferenced using the Control Point Setup function of INTERGRAPH's MGE software. A graticule was generated using the Grid Generation function of the MGE software. The linework and the graticule were merged into a mosaic; and edgematching was performed, all using MGE. The graticule was the source of the digital, 7.5-minute quadrangle boundaries. After completing the line cleaning, the digital geologic quadrangles were translated into ArcInfo coverages for topology building. These topologically correct polygon coverages were then translated into ArcView shapefiles. Finally, the database for each shapefile was populated with attributes using ESRI's ArcView software.

INTRODUCTION

As part of a contract with the U.S. Army, the Louisiana Geological Survey (LGS) recently completed the geologic mapping of ten 7.5-minute quadrangles (figures 1, 2) encompassing the Fort Polk Military Reservation and Peason Ridge Military Installation in west-central Louisiana (McCulloh and Heinrich, 1999). The main purpose of the work was to provide information essential to the Army's ongoing environmental programs at Fort Polk, but it also enlarged upon recent work by Hinds (1997a, b; 1998a-c; 1999) and extended the geologic mapping efforts of the LGS in this part of the state. This paper sketches a chronicle of the geologic mapping, and describes the process formulated for its production as a GIS.

Figure 2 shows a mosaic of the surface geology mapped for the 10 quadrangles in the study area. We also compiled economic geology, as a derivative of surface geology and from field notes, using a mixed representation of polygons and points; and geologic hazards, found to comprise only flooding, which was recompiled as polygons from Federal Emergency Management Agency

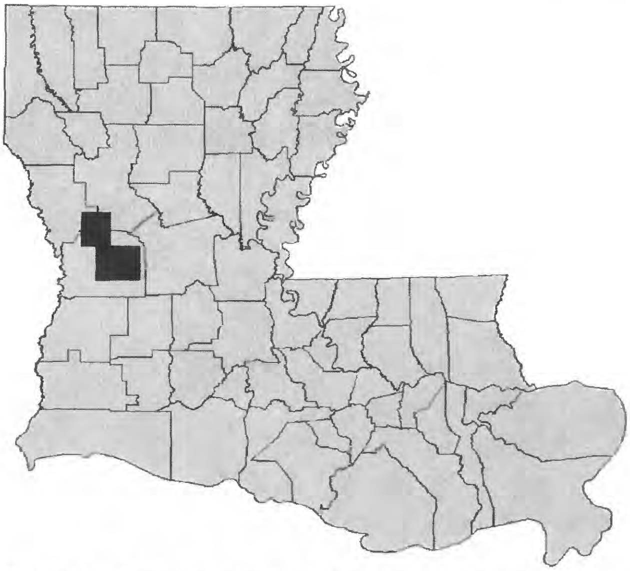


Figure 1. Location map of 10 quadrangles composing Fort Polk study area.

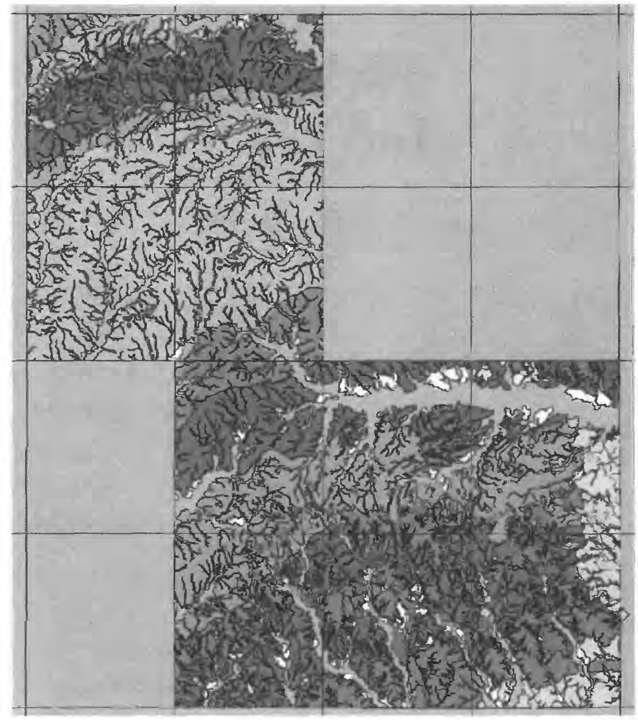


Figure 2. Surface geology mosaic of Fort Polk study area. The comparatively narrow and complexly branching polygons are the (Holocene, undifferentiated) alluvium.

(FEMA) flood maps. Because both of these layers are themes ultimately derived from aspects of the surface geology, the latter was the main focus of our efforts. This was our first 7.5-minute geologic GIS compilation in which we compiled both the geologic data and the GIS. Although we had a keen interest in developing a standard methodology for future projects, we were constantly on the learning curve in this first such collaboration. The data were compiled as individual quadrangles at 1:24,000, but the GIS was designed such that the corners and boundaries of adjacent quadrangles coincide seamlessly without breaks, regardless of the scale of viewing the data. (This design feature is discussed in greater detail below.)

In our field work we encountered problems of accessibility. First, exposures of the geologic map units of interest to us are scarce. In most places they are covered by thick soil, vegetation, and surficial deposits; and most of the surficial deposits in the study area are not diagnostic of the underlying map units. Most exposures are associated with roads and streams; those associated with roads are more accessible and for our purposes were more abundant, but a majority of them comprise small and highly inconspicuous stretches along the lower reaches of road ditches, and lack discernible macroscopic or mesoscopic depositional structure. Another access problem derived from restrictions characteristic of military property: timing of our access to various portions of the study area had to be scheduled to accommodate training rotations, and some parts of it, such as impact areas, are permanently off-limits. Finally, much of the study area not on military property is controlled by timber companies and hunting clubs, and is not easily accessible.

A majority of the pre-Plio-Pleistocene section comprises Miocene strata that consist of continental/fluvial facies, near the transition to a deltaic regime. This accounts for the alternation of sand- and silt-rich lithofacies, which contain some gravel, with finer-grained units interpreted as brackish-water facies—which is the basis for subdivision of the Miocene into mappable units of formation rank (though they are traditionally referred to as members of the Fleming Formation). The finer-grained units are the thicker tongues that actually extend all the way updip to the outcrop. Some of the Oligocene and lower Miocene section contains beds of silicified rock, including some that are quarried locally, but most of the sediment in the study area is poorly consolidated to semiconsolidated. The most significant unconformity is that between Plio-Pleistocene and Miocene strata, which is marked in places by indicators that may include either or both of the following: a distinctive purplish alteration color in fine-grained Miocene sediment immediately beneath the unconformity; and rip-up clasts of the purplish mud in the overlying Plio-Pleistocene.

METHODS

Design Format for Source Materials

The scarcity of exposures in the study area was such as to give the geologic-mapping work a statistical character, unlike the geologic mapping of areas in semiarid and arid settings. So in addition to making notes in field books, we put notes in the field directly on standard topographic quadrangles, corresponding to the localities where we found exposures. We later inked these notes, not just for permanence, but to increase contrast for photocopying (figure 3). When the field work was nearly done, we made full-size photocopies of the field quadrangles with the inked notes. On these we color-coded the exposure locations with different-color highlighting based on our interpretation of which of the geologic map units they represent, to facilitate eventual contour-mapping of the distinguished areas as polygons.

While the field work was underway, we simultaneously interpreted alluvium directly from the topographic base maps, for two principal reasons. First, this is in fact the most consistent and systematic way to interpret the alluvium, which is resolved as a continuous network of low-relief bottomland landforms. And second, alluvial deposits tend to be overgrown with vegetation, so effective field access to alluvium is even more of a problem than with the other geologic map units. We began this alluvial mapping early in the project because, as is clear from figures 2 and 4, alluvium constitutes a very large proportion of the total linework. We traced this linework on vellum, which was a continuation of our methodology from previous non-GIS projects, and we completed this component long before the field mapping of the other units was brought to a close. Polygons of the nonalluvial (suballuvial) geologic units were ultimately created by contour-mapping in detail the areas that had been distinguished initially with color highlighting on the full-size quadrangle photocopies. We traced this linework, plus faults, in different colors on mylar.

This was the point at which the GIS compilation picked up the process from what had been essentially field-mapping procedures before. Mylar and vellum overlays were formatted with corner ticks and 2.5-minute reference crosses in black ink. Both were also formatted with approximated quadrangle boundaries or graticule lines, which for the mylar overlays was done using blue ink. After the hardcopy overlays with these two different types of linework were manually edge-matched and labeled, scans of them were used as source data in the digitizing process, and the two were ultimately combined in the GIS. The composite linework was edited to show the alluvium occluding the other surface-geologic units, as it does in reality. The following section discusses in detail the specific aspects of the GIS compilation.

GIS Compilation and Development Process

As mentioned above, linework delineating the alluvium was compiled on vellum (figure 4). This was done long before designing the GIS data compilation process. Unfortunately, like paper, vellum can shrink differentially, through time. Mylar is much more stable. When the senior author began to design the GIS process, we agreed for all future work to use mylar 7.5-minute quads as sources and to compile the nonalluvial geologic contacts on mylar. This included the remainder of the Fort Polk project. At this point, therefore, the geologists began the nonalluvial compilation on mylar, while the GIS team began to scan and digitize the alluvial linework from the vellum sheets.

The digitizing effort was performed with the automated line following function of INTERGRAPH'S GEOVEC software. GEOVEC runs on top of Bentley's MicroStation and INTERGRAPH'S Base Imager; and it employs the MicroStation Feature Collection System. The initial digitizing effort consisted of three phases:

- initially, all lines were digitized, smoothed and filtered;
- next, flags were placed where digitizing errors were made; and
- finally, corrections were made where the flags had been placed.

Once the digitized lines had been corrected, the line cleaning process began. These tasks were all performed within the INTERGRAPH MGE environment. First, Duplicate Line Processor was run on each alluvium design file. Duplicate Line Processor eliminates all duplicate lines and breaks all line intersections.

With the intersections broken, for each control corner or cross, we could then georeference the alluvium by snapping to the intersection. All of the georeferencing was performed within the MGE environment, using the Control Point Setup function. All eight control points, at 2.5-minute intervals, were used for each quad as we georeferenced them in the Louisiana "State Plane" Coordinate System, North Zone, as referenced to the North American Datum, 1927. This was the Lambert Conformal Conic projection of the source quads. At this point, all of the digital alluvium contacts were *geospatial.*

We could now convert each digital quad file into the Universal Transverse Mercator coordinate system, as referenced to the World Geodetic System, 1984 (WGS84). This was done to satisfy the specifications of the U.S. Army Corps of Engineers for the deliverable GIS product. For quality assessment of the georeferencing process, we generated a graticule in the UTM coordinate system and overlaid it with the converted alluvium files. The graticule was created by using the Grid Generation function of MGE. Then we turned our attention to the nonalluvium (figure 5).

We digitized the scanned images of the nonalluvium quads by following the very same process that we used for the alluvium. Once the nonalluvium quads were georeferenced, they were overlayed with the alluvium, as reference files. Now, for the first time we were able to see all of the digital surface geology contact lines in their proper con-

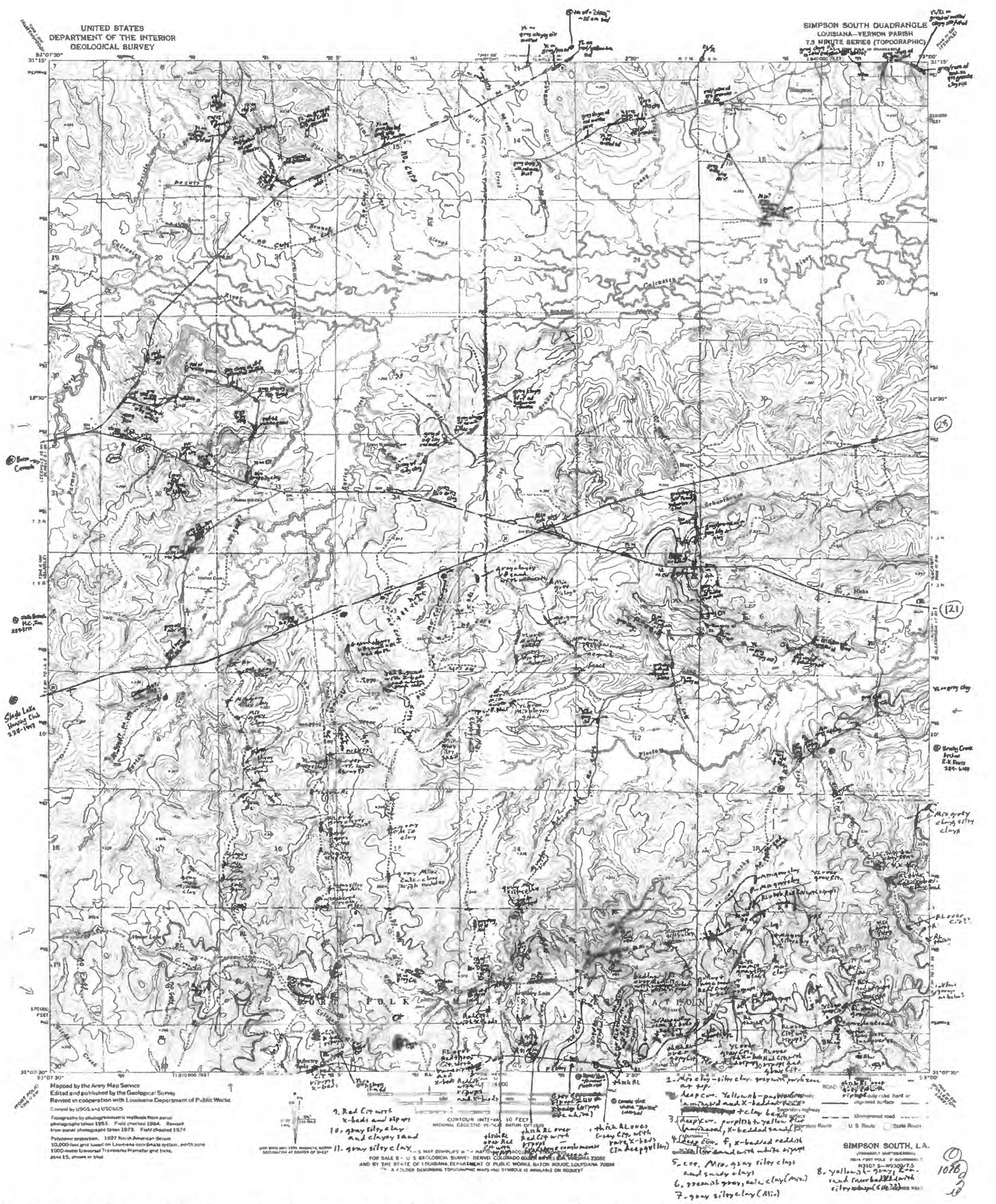


Figure 3. Copy of field quad with notes, 1:24,000-scale Simpson South quadrangle.

text, both as individual quads and in mosaic. So now, full-scale color plots could be made for the geologists to review.

At this point we should mention that, as a direct result of experience gained from this project, both alluvium and nonalluvium lines will be drawn manually on the same mylar sheets in future projects. This will greatly minimize the labor involved in the georeferencing and edgematching processes.

The results of the reviews by the geologists were mylar sheets of both the lines to be added and the lines to be deleted. The lines to be added were digitized, cleaned,

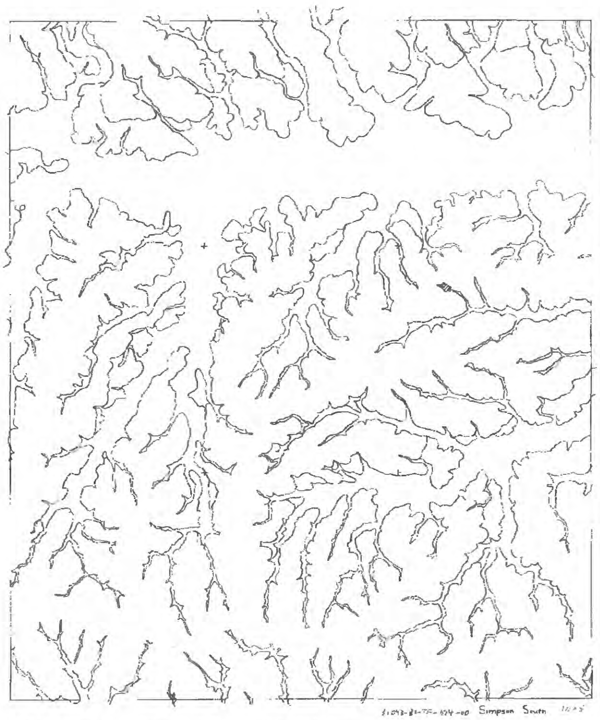


Figure 4. Scan of alluvial linework, Simpson South quadrangle. The comparatively narrow and complexly branching polygons are the (Holocene, undifferentiated) alluvium. Also mapped on the same overlay are low terraces—the adjacent smaller, more equidimensional polygons.

Figure 5. Scan of nonalluvial linework, Simpson South quadrangle.

georeferenced and overlayed with the alluvium and nonalluvium. Then flags could be placed around lines that were to be deleted. At this point in the GIS process, all the needed lines had been digitized, georeferenced, and reviewed by the geologists. The flags led us quickly to the lines to be deleted. The time had come to stitch all the panels and patchwork together, for edgematching—or had it?

In the past, the senior author has been quite frustrated, as no doubt have been many readers, to find that digital vector quadrangles don't usually mosaic seamlessly. Even though they have been edgematched, there will usually be a gap between adjacent quadrangles when one zooms in beyond the resolution of the data. In order to prevent the occurrence of these gaps we overlayed the graticule which we had previously generated using MGE's Grid Generation function. *Now*, the time *had*, finally, come to stitch all the digital linework together. We performed this operation by creating a new blank design file of the same projection, overlaying it with all of the design files for each of the ten quadrangles, turning on all layers in all files, and performing a fence copy of all the linework into the new blank design file.

Next, MGE's End Point Processor was used to flag all dangling ends for the alluvium and nonalluvium layers. All other layers were turned off, including the quad boundaries. And, with the interactive guidance of the geologists, the contacts were manually edgematched. This all-inclusive vector line file, of almost 30 MB, will be archived, as the master mosaic, for potential future data development, as well as for documentation of this work. From this master mosaic design file, only the desired layers were fenced copied into ten new UTM, WGS84 design files. These layers included the alluvial and nonalluvial contacts, along with the graticule. From these layers the final polygons would be assembled.

After running the Duplicate Line Processor on each of these ten new design files, there were no duplicate lines, and intersections had been broken where the contacts crossed the graticule. Finally, the short segments outside the graticule were deleted from each of these new digital quads. At this point in the GIS compilation process, the line development was complete. The next task was to create topology.

Since our plan was to ultimately populate the database within ESRI's ArcView environment, our next step was to translate the final ten INTERGRAPH design files into ArcInfo coverages. We used ArcInfo's IGDStoARC translator to make the translations. After the translation, the projection had to be defined, since the IGDStoARC translator cannot translate the INTERGRAPH projection information. We then used the "Build" command in ArcInfo to construct polygon topology from the contact lines. If the process failed, that indicated that some duplicate lines still remained in the digital quad. In such a class, MGE's Duplicate Line Processor would be run again on the final design file, before attempting to translate again and build topology. Once polygon topology was constructed for the ArcInfo coverage, we simply "Added" it to an ArcView View window and "Converted" it into an ArcView shapefile.

Meanwhile, the GIS team had requested that the geologists label the review plots with the geologic-unit abbreviations. These labels were used by the GIS team as the source from which to populate the ArcView shapefile database. After populating the database with abbreviations, we sorted the "Area" field into ascending order, to facilitate finding any slivers that might exist. These slivers were "Unioned" with adjacent unit polygons, one by one, in ArcView. Finally, customized hues were created in ArcView for each geologic unit type. ArcView could then automatically render all the unit polygons, for each of the ten shapefiles, by reading the unit abbreviations within each shapefile database. At this point, the most difficult and time-consuming tasks were over. The remainder of the tasks began with one that we refer to as "polishing the databases." This was followed by creating ArcView layouts for maps-on-demand; creating metadata files; composing acknowledgments; formulating readme files; and recording and packaging of the CD-ROM. Discussion of these tasks is beyond the scope of this paper and, therefore, they are not here discussed in detail.

ACKNOWLEDGMENTS

The work discussed herein was prepared by the Louisiana Geological Survey for Prewitt & Associates, Inc., Austin, Texas, under contract to the U.S. Army Corps of Engineers, Fort Worth district. We thank the Army Corps for funding this continuation of our geologic mapping efforts, and for permission to present this paper at DMT'00; and we thank the DMT organizers at USGS and the University of Kentucky for providing space on the program for our presentation at a late date. The junior author conducted the field work and geological investigation jointly with Paul V. Heinrich, Research Associate. The senior author designed the Geographic Information System and supervised its development. He was assisted by the following persons, who contributed to the GIS data compilation: David W. Griffin, Research Associate; Meenakshi Gnanaguruparan, Graduate Assistant; Mohiuddin Shaik, Graduate Assistant; Louis Temento, Graduate Assistant; Barbara Olinde, Student Worker; Sait Ahmet Binselam, Graduate Assistant; Jesus G. Franco, Research Associate; Asheka Rahman, Graduate Assistant; Tiffani Cravens, Student Worker; Andrew Beall, Graduate Assistant; Xiaojue Pan, Graduate Assistant; and Steven J. Rainey, Graduate Assistant. Weiwen Feng, Research Associate, compiled the metadata for the GIS files on the CD-ROM.

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Three-Dimensional Geologic Mapping of the Villa Grove Quadrangle, Douglas County, Illinois

By Curtis C. Abert, C. Pius Weibel, and Richard C. Berg

Illinois State Geological Survey
615 East Peabody Drive
Champaign, IL 61820
Telephone: (217) 244-2188
Fax: (217) 333-2830
e-mail: abert@isgs.uiuc.edu

ABSTRACT

Geologic formations have variable lateral extents, thicknesses, and/or depths below the land surface. The three-dimensional (3-D) nature of geologic formations has been difficult to portray on traditional 2-D geologic maps. Advances in computing technology and software have made it possible to model the 3-D nature of geologic materials and subsequently, to portray this information on 2-D printed maps. The real power of modeling 3-D geology lies within the digital environment. However, digital simulations of 3-D geology do not come without cost. High-end computers and software are perhaps the most tangible costs. Intangible costs include personnel, data collection and quality assurance/quality control (QA/QC). This paper will present some of the difficulties associated with constructing a detailed 3-D model, as well as highlight the benefits and uses of detailed 3-D geologic modeling of the Villa Grove 7.5-minute quadrangle in Douglas County, Illinois.

INTRODUCTION

Purpose of the Mapping

The Illinois State Geological Survey (ISGS) has a long history of using Geographic Information Systems (GIS) for geologic mapping and database development (Krumm et al., 1997). Recent projects at the ISGS have focused on detailed 1:24,000-scale mapping of 7.5-minute quadrangles. The primary objective of the mapping project is to thoroughly map the geology of a quadrangle in three dimensions (3-D) and provide a comprehensive suite of maps to serve the needs of regional and local planners and other governmental officials, business and industry, and private citizens. The Villa Grove Quadrangle was chosen as a pilot project to develop and test large-scale 3-D mapping methods for producing a 3-D map atlas. Included in the atlas are basic geologic maps of surficial geology, drift thickness, bedrock topography, and bedrock geology, as well as derivative maps of aquifer resources, aquifer sensitivity, coal resources, aggregate resources, and others. A derivative map is an interpretation of geologic data for specific environmental or resource purposes. The basic geologic maps were both derived from, and provided data for, the 3-D geologic model.

Regional Geologic Setting

Low-relief unlithified materials deposited during the Quaternary Period overlie Paleozoic bedrock within the Villa Grove Quadrangle. The unlithified Quaternary materials are predominantly glacial diamictons (tills) related to three glacial episodes, but also include glaciofluvial (sand and gravel) and glaciolacustrine (silt and clay) materials as well as materials deposited and formed during interglacial episodes (loess and soils) and the present post-glacial episode (Hansel et al., 1999). Elevations of the land surface range from greater than 216 meters (708 feet) to less than 187.5 meters (615 feet) for approximately 28.5 meters (93 feet) of relief.

The Villa Grove Quadrangle is situated on the eastern limb of the asymmetrical doubly plunging Tuscola Anticline. Dips of bedrock units are generally less than 1 degree to the east or east-northeast (Weibel and Lasemi, 2000). The topography of the bedrock surface is one of the more significant mapped surfaces, because it defines the bottom of the Quaternary units and the top of the Paleozoic units. Elevations of the bedrock surface range from greater than 600 feet to less than 425 feet (175 feet of relief) (Weibel, 1999). The prominent valleys and uplands of the bedrock surface were most likely formed by a pre-glacial drainage network that was subsequently modified during early glaciations (Melhorn and Kempton, 1991 and Soller et al., 1999). Many bedrock valleys in Illinois are partially filled with sand and gravel, which can be important regional and local aquifers.

CONSTRUCTING THE 3-D GEOLOGIC MODEL

Input Data

The Villa Grove 3-D geologic model was constructed primarily from data extracted from logs of water wells, geologic test borings, engineering borings, and mineral test borings. Additional data included surface elevation data (digital elevation model), geologic map data, soil test borings, soil data, and isopachous (thickness) maps from previous studies. Data extracted from the logs of wells and borings include formation description, lithology, depth, and thickness. Data quality ranged from very good for the geologic test borings to uncertain or poor for some water well data, and the spacing and density of wells varied significantly over the quadrangle. For modeling the Quaternary deposits, a total of 181 data points were used. The data points were generally within 2,000 to 3,000 feet of one another, but some were more than 7,000 feet from the nearest other data points (figure 1). Data density ranged from 24 points to zero points per Public Land Survey section. Coordinates, elevations, and properties of data points were assembled into ASCII files and imported into EarthVision, a geologic modeling software.

Modeling Hardware and Software

The ISGS used a combination of GIS (ArcInfo, ESRI) and 2-D and 3-D modeling software (EarthVision, Dynamic Graphics Inc.) to construct the 3-D geologic model. Oracle (Oracle Corp.) was used to manage the water well and boring database. The primary platforms used for analysis and display of data and models were Sun (Sun Microsystems, Inc.) Ultras with Creator3D graphics cards, and Silicon Graphics (Silicon Graphics, Inc.) workstations.

Basic Modeling Assumptions

A traditional 2-D geologic map is necessarily an abstraction of reality. The true complexity and detail found on or within the Earth cannot be portrayed on such a map. A 3-D computer model is another abstraction of reality. Features that can be portrayed on a traditional geologic map must be further generalized to produce a computerized model due to limitations in computer hardware and software. The replication of a traditional 2-D geologic map in a 3-D geologic model is difficult. Variables such as map scale, screen resolution, amount of input data, model dimensions, and cell size will affect the resulting 3-D model. However, 3-D geologic models can be used in the construction of traditional 2-D geologic maps.

EarthVision uses a 3-D grid to store, interpolate, and build geologic models and the geologist must give thought to determining the appropriate cell sizes in the X, Y, and Z dimensions. For the Villa Grove model, an X/Y cell size of 1,320 feet (1/4 mile) and a Z cell depth of 20 feet were chosen to model all materials to a depth of 1400 feet below mean sea level. A more detailed model of just the unlithified Quaternary deposits had a Z cell depth of 10 feet. The cell spacing was determined by considering the accuracy of data point locations and their density, as well as software and hardware limitations. Models produced with a grid that is too coarse may oversimplify the geology, but models with finer grids produce much larger files and take more computing resources to calculate. Also, extrapolation artifacts may be introduced in the model if there are many grid cells interpolated between distant data points.

Another consideration in building 3-D geologic models is the extent of the input data. Where data are sparse, especially near the edges of the map area, modeled surfaces may be unreasonably extrapolated. Therefore, it is advantageous to model an area that extends beyond the actual area of interest. The added data points located in the "buffer" area provide much-needed edge control of extrapolation in the model. Excessive extrapolation near the edges of the buffer area can be removed from subsequent displays, leaving only a reasonable model for the main study area. In constructing the Villa Grove 3-D model, we used a buffer area of up to 3 miles.

Types of Geologic Models

Two basic types of models were created during the project — stratigraphic models that show the 3-D geometry of geologic units, and lithologic models that show variations of the texture of materials within geologic units. The stratigraphic models were created by first modeling stratigraphic horizons as 2-D grids. Generally, shallow units have more control than deeper units. However, this was not the case within the Quaternary deposits compared to the uppermost bedrock units. The horizons between the Wisconsin/Illinois, and Illinois/pre-Illinois glacial episodes were defined by 36 and 22 points, respectively, but the topography of the bedrock surface was defined by a total of 170 points (91 in the quadrangle). The surface of the deepest modeled bedrock unit, however, was defined by a total of 33 points (only 4 of which were actually within the quadrangle). Additional control could be achieved on the deeper bedrock surfaces by using better-defined upper sur-

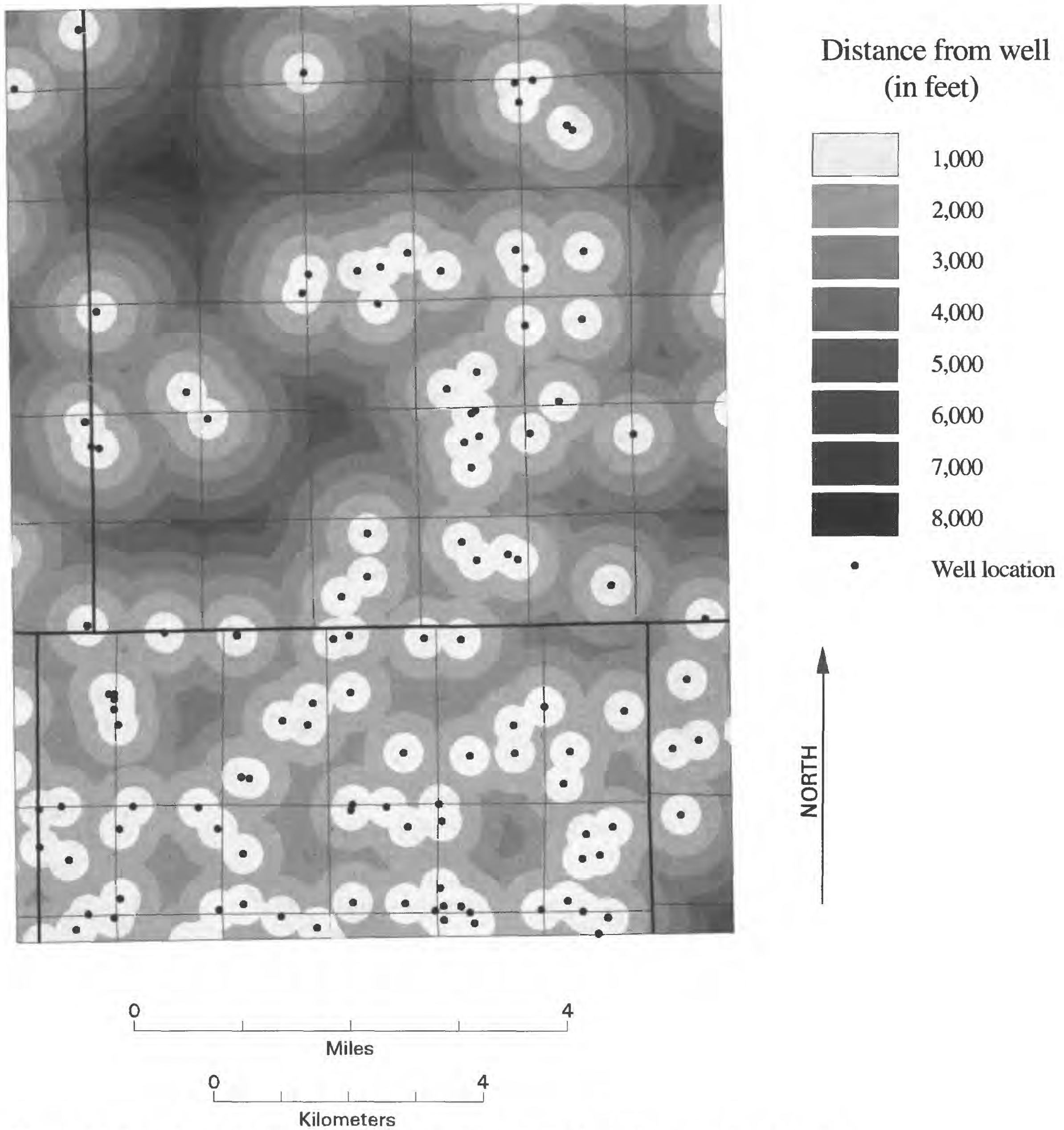

Figure 1. Locations and distances between points within the Villa Grove Quadrangle.

faces as intermediate or "helper" surfaces. Where data were sparse on deeper surfaces, the surface was modeled to somewhat parallel upper surfaces. This technique is appropriate only for conformable geologic units with fairly consistent thickness. In Illinois, bedrock units are likely to have fairly consistent thicknesses over a 7.5-minute quadrangle size mapping area. Figure 2 shows the stratigraphic model for the bedrock units in Villa Grove Quadrangle.

Generalized lithologic models were prepared for the Quaternary materials, consisting of the thickness and extent of sands and gravel layers (potential aquifers) and diamictons (aquitards). Lithologic descriptions from the well and boring database were classified as either coarse-grained or fine-grained, and numeric codes (1 for fine grained, 3 for coarse-grained) assigned to the units. The numeric lithologic codes, along with coordinates and elevations of the units, were loaded into EarthVision to create a 3-D property model. EarthVision can create 3-D contours or "shells" of property values in 3-D space. In our models, the contour shells ranged in value from 1 (fine-grained) to 3 (coarse-grained). The contour shell with the value of 2 was determined to be the "contact" between the fine and coarse-grained lithologies. Variables within the gridding algorithm were used to constrain extrapolation. Further control on extrapolation was gained from limiting the interpolation of 3-D contours to specific geologic units.

Figure 3 shows the generalized lithologic model of Quaternary deposits within the Villa Grove Quadrangle.

CONCLUSIONS

Computerized modeling of the 3-D nature of geology can lead to a much greater understanding of the relationships of units, but the geologist's participation in the iterative process of modeling provides essential feedback to the model that ensures that the final result is a geologically reasonable interpretation of the available data. While it may not be appropriate in all geologic settings, development of 3-D lithologic property models have proven to be a useful tool in mapping Illinois' geology. Stratigraphic models can be used for nearly any geologic setting. Several advantages and disadvantages of the 3-D geologic modeling include the following.

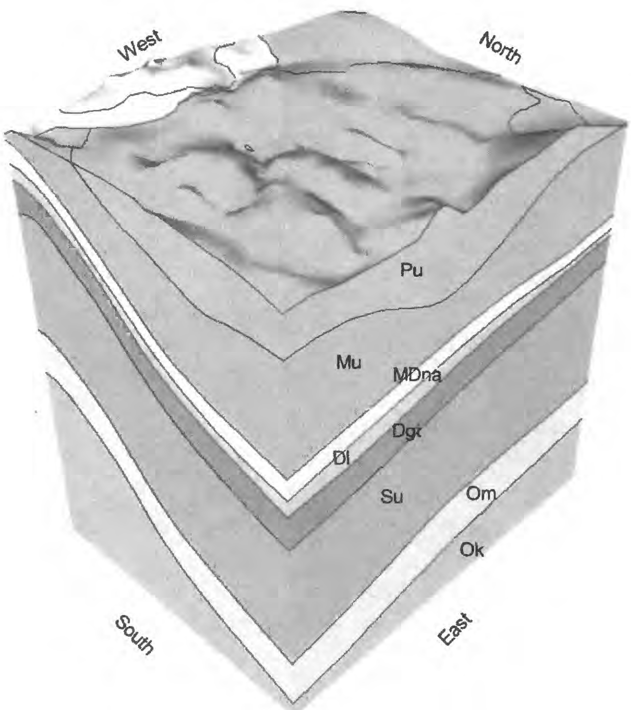

Figure 2. Three-dimensional stratigraphic model of the bedrock in the Villa Grove Quadrangle. Vertical exaggeration 25X.

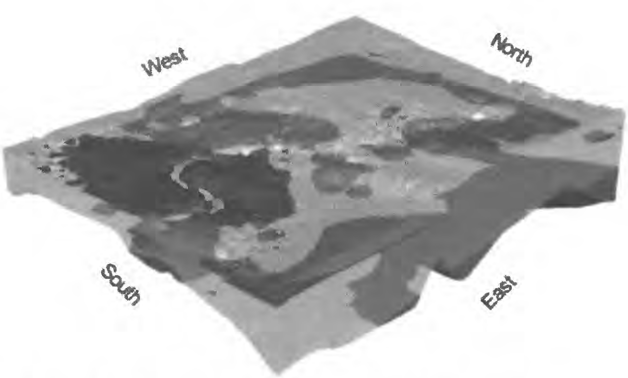

Figure 3. Semi-transparent view of the three-dimensional property model of Quaternary deposits in the Villa Grove Quadrangle, showing lithologic variations. Coarse-grained material exposed at the land surface or "exposed" on the model sides are shown in dark gray. Coarse-grained material in the subsurface are shown in medium gray. Fine-grained material is shown in light gray. Vertical exaggeration 40X.

Advantages

- Many modeling systems do not allow preference to be given to "better" data – all data are treated equally. This can allow for an unbiased or holistic view of the 3-D relationships of the data.
- Computerized 3-D modeling allows for updates or modifications of the model to be made when additional data are available or changes in modeling parameters are tested.
- Many different kinds of data can be combined and used to produce a 3-D model.
- Data can be extracted from 3-D models to produce other products (for example, a stack-unit map can be produced)
- 3-D views of geology are more easily understood than traditional geologic maps by the general public.

Disadvantages

- Many modeling systems do not allow preference to be given to "better" data – all data are treated equally. Geologists generally have more confidence in certain data than in others, and would like to give more weight to better data.
- Computerized 3-D modeling allows for repeated updates or modifications of the model with additional data or changes in modeling parameters. The update process may require significant effort. It is a common misconception that "because it is digital, it must be easy to do or require minimal effort."

The best geologic models integrate the geologist's logic and knowledge with the impartiality of the 3-D modeling software. The ability of the computer to manipulate large amounts of data is best used when it is paired with a geologist's ability to determine what is "real."

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What Visualization Contributes to Digital Mapping

By Paul J. Morin

Department of Geology and Geophysics
University of Minnesota
310 Pillsbury Drive
Minneapolis, MN 55455
Telephone: (612) 626-0505
Fax: (612) 625-3819
e-mail: lpaul@umn.edu

ABSTRACT

Scientific Visualization, the artistic expression of scientific data, has much to contribute to Digital Mapping, the creation of maps with computers. Both have many of the same goals including the understanding of data, and the creation of educational and reference materials. The key difference is the divergent paths the fields have taken to get where they are today. Digital mapping has been far more successful in being used as a day-to-day tool and providing a core set of tools and technologies. Three spatial dimensions and change over time are probably the two most important factors that Scientific Visualization has to offer the field of digital mapping. In addition, scientific visualization has embraced virtual reality, and is finally becoming available to its users through low cost, high performance, hardware.

3D AND TIME DEPENDENCE

Modern visualization arose from the computational scientist's need to visualize the large simulations produced by the supercomputers of the period. This need has led to the assumption that all scientific data is in three-dimensions and is time dependent, sometimes to the exclusion of 2D visualization. An example of three dimensional visualization software is the program Brick of Bytes (BOB) by Ken Chin-Purcell. This application written for Silicon Graphics, Inc. (SGI) workstations reads 3D raster files and quickly displays data without re-rendering surfaces. Each volume element (voxel) is assigned a color and degree of opacity. The data is drawn beginning with the voxels farthest from the viewer's eye and ending with those that are closest. The result is an image with a cloud like appearance.

The primary issue that BOB addressed was large 3D datasets, as shown in figure 1. Many of the animations that used BOB had several thousand timesteps that were individually larger than 512x512x512 bytes with total a total size of over 100 gigabytes. BOB's advantage was that it was written as a simple turnkey program that gave users access to their data in minutes. Though BOB was written nearly 10 years ago many variants of it are still being used.

EVOLUTION OF GRAPHICS TECHNOLOGY

A hierarchy of graphics standards strongly influences and benefits Scientific Visualization and 3D graphics in general. Open GL (OGL) was developed by Silicon

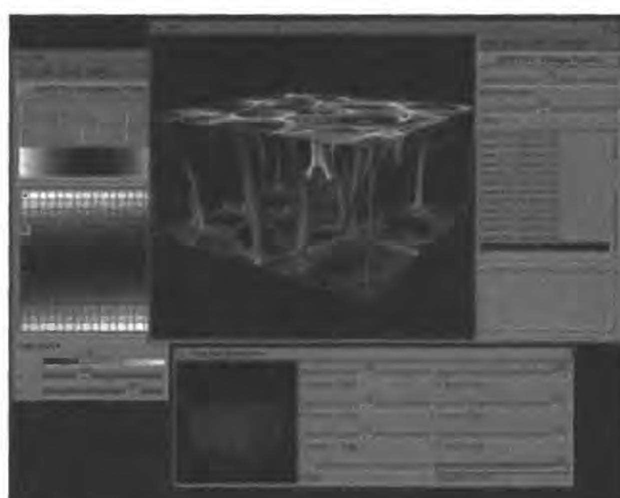

Figure 1. A screenshot of a mantle convection simulation using BOB.

Graphics, Inc. and is the primary programming interface used for creating visualizations embedded in applications. Nearly all visualization software uses some form of the OGL language to implement their 3D graphics. It provides a platform-independent Application Programming Interface (API) for creating 3D graphics on a large number of workstations and personal computers.

With recent graphics hardware advances, modern scientific visualization is being driven to the desktop and into the hands of more users. What once required a mid-range graphics workstation can now be performed on a consumer grade Windows PC. The primary factor we have to thank for this drop in price is the computer game industry and most notably the first-person shoot-em-up games, such as Doom.

Table 1 contains a comparison of three very different graphics platforms. The Onyx 2 is the computer of choice for high-end visualization and virtual reality. It is available in a desk side version that is about half the size of a desk or in a format the size and shape of a refrigerator. The PC is a standard Intel/Windows computer with a high-end consumer graphics board. The Sony Playstation 2 is the newest generation of home video game computers.

A few items in Table 1 are worth noting. Even though the Onyx 2 has CPU clock speeds that are well below those manufactured by Intel, they are still faster in floating point calculations because they are primarily designed for use in science and engineering. The Sony Playstation 2 and the Windows PC have significantly smaller memory capacity and, more importantly, the speed that the CPU can access the memory is more than an order of magnitude slower than the Onyx 2.

Probably the most interesting benchmark is the maximum polygon rate of each of the graphics subsystems. This is a relatively new development for the increasingly low-cost systems to rival the performance of high-end systems. The maximum polygon rate is a significant measure, as polygons comprise almost every object observed within a 3D scene. If more polygons are pushed to the screen, objects can be more elaborate and responsive when being manipulated by a user. Moreover, these statistics are for *texture mapped polygons*. That is, polygons that have been painted with a raster image. The ramifications of texture mapping for practitioners of digital mapping is very important. It is the simplest way to texture map a DEM with any geo-referenced raster data.

It is worth noting that the Macintosh series of computers are rarely used in 3D scientific visualization. The primary reason is that, until recently, Apple has not opened the Macintosh platform to third party graphics boards that support 3D graphics standards, such as OGL.

GENERIC VISUALIZATION PACKAGES

There are three highly flexible 3D visualization packages currently available; Advanced Visualization System (AVS) and Iris Explorer are commercial, whereas Open Data Explorer is now free and has been placed in open source by IBM. Figure 2 shows Explorer used for digital mapping. These programs provide the most generic frameworks for data manipulation, data import, and the customization of existing features by a programmer through a common programming interface, but they are not customized for a given science. In other words, these packages are not plug and play.

All three visualization packages are used in a very similar way. Users create a flow chart within a sophisticated graphical user interface, consisting of modules connected by paths that direct the flow of data. This "data flow" model for constructing visualizations is very quick and powerful, but it has one primary drawback. It makes many copies of data and requires a large amount of RAM and hard disk space to run. It is common to have hundreds of megabytes of RAM on any machine running these programs. The advantage of using this data flow model is that modules can be quickly rearranged, added, written, and adapted without knowing the entire system.

Why Isn't There More Software?

Economic factors are the primary reason for the shortage of visualization software on the market. Many of the currently available commercial applications were devel-

Table 1. Comparison of three types of computers with powerful graphics subsystems.

	SGI Onyx 2 with Infinite Reality Graphics	High end PC with a Asus 6800 Graphics Card	Sony Playstation 2
CPU	250 MHz +	1 GHz	300 MHz
RAM	Up to 16 gigabytes	Gigabyte +	32 MB
Max Polygon Rate	10 Million per pipeline/sec	7 Million/sec	20 Million/sec
Stereo Images	Yes	Yes	No
Communication	Any	Any	PCMCIA Card
Weight	400 lbs.	20 lbs.	Under 5 lbs.
Cost	$50,000-Million+	Less than $4000	$300-$400

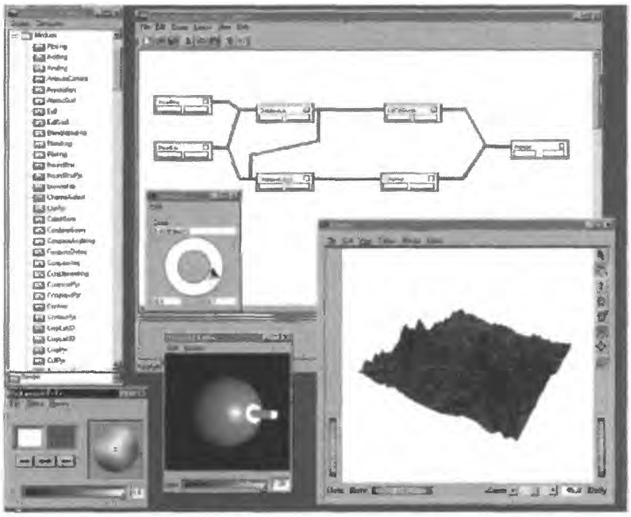

Figure 2. A remote sensing image painted on a DEM using Iris Explorer on Windows NT. Note the modules in the flowchart-like interface.

Figure 3a. A user in a CAVE (figure courtesy Fakespace Systems, Inc.).

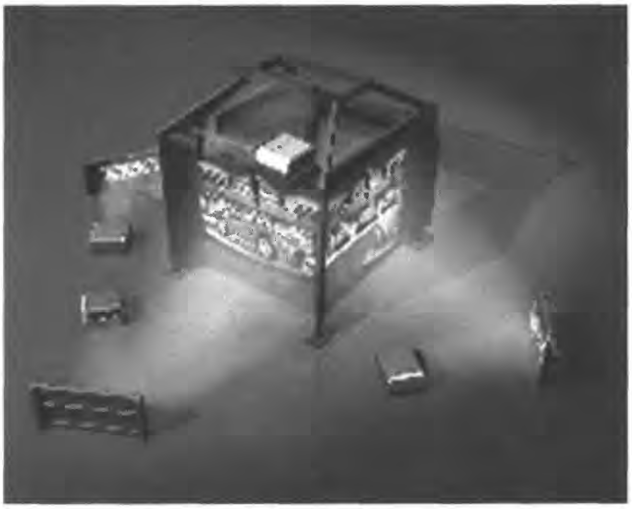

Figure 3b. A schematic of the exterior of a four walled CAVE (figure courtesy Fakespace Systems, Inc.).

oped on graphics workstations that cost a minimum of $10,000 and sometimes exceeded $100,000. Users found easy justification for software costing more that $10,000 when it compared favorably to the original price of the computer. But when the same software is available on a Windows or Linux PC, the pricing structure is turned on its head. How many of us can justify a $10,000 application on a $2000 computer? Now that this shift to lower priced, high performance computers is in progress, the best we can do is use the available tools and wait for the market to adjust to the new realities.

VIRTUAL REALITY

Over the past decade, the large amount of data available in 3D, time dependent data sets was the primary problem in scientific visualization. As datasets increase in size it becomes an increasing challenge to manage, display and interpret. One approach has been to put a user within a synthetic environment, or virtual reality (VR), to trick the senses into interpreting data as they would the real world. Perhaps the most dramatic, immersive VR technology is the CAVE developed in the Electronic Visualization Lab at the University of Illinois, Chicago and Champaign-Urbana.

A CAVE consists of a large graphics workstation, which displays stereo images in a 10'x10'x10' room with up to four walls, the floor, and ceiling (Fig. 3). A small number of users (usually under 3) can walk within the objects being displayed, giving a sense of immersion.

CAVEs are expensive. A full 6-sided CAVE with a powerful SGI workstation can exceed one million dollars including the projectors, computer, screen, and software. Interestingly, the barrier to lowering the cost of this technology is not the cost of the computers, but the cost of the projectors. The most inexpensive projector that supports stereo images is $20,000. Also, the usefulness of a multi-wall CAVE is limited to a small number of people that can crowd around the user with the position sensor on his stereo goggles.

An alternative is a single wall CAVE, also called a WorkWall (Fig. 4). This configuration uses less expensive hardware and gives a larger group of people more of a

Figure 4. An artist's conception of a WorkWall (figure courtesy Fakespace Systems, Inc.)

shared experience. WorkWalls are finding their way into design labs and classrooms for just this reason.

Another lower cost alternative is to use one of the new breed of stereo boards designed for the Advanced Graphics Interface (AGI) slot in a Windows PC. Boards such as the Asus 6800 and Elsa Erazor X cost less than $350 with stereo goggles. The Geology and Geophysics Department of the University of Minnesota is exploring installing these graphics boards in every PC in the physical geology lab rooms. Students will add the exploration of earthquake hypocenters and topography in 3D to traditional labs on mineral identification and map reading.

REAL-TIME DELIVERY ON THE WEB

Perhaps the most powerful way to use Scientific Visualization is over the Internet, without specialized software, through a browser. The Space Physics and Aeronomy Research Collaboratory (SPARC) is a good example. SPARC is a framework for collaboration that presently has over 150 feeds from data sources as diverse as satellites, ground based radars, and models. Visualizations are produced automatically and in near real time as data arrive and are automatically pushed to the user's browser (Fig. 5).

The next generation of Internet delivery of visualization currently under development will allow users to construct visualizations from scratch using data sources distributed around the Internet and delivered as GIF images, QuickTime movies, and Virtual Reality Markup Language (VRML) objects (Fig. 6) using the CosmoPlayer plugin by Computer Associates International or the 3SpaceAssistant application and plugin from Template Graphics Software, Inc. The aim is to remove most, if not all, of the visualization software from the user's computer and to produce

Figure 5. The SPARC opening page. Any of the pages can be customized to show any one of numerous data sources.

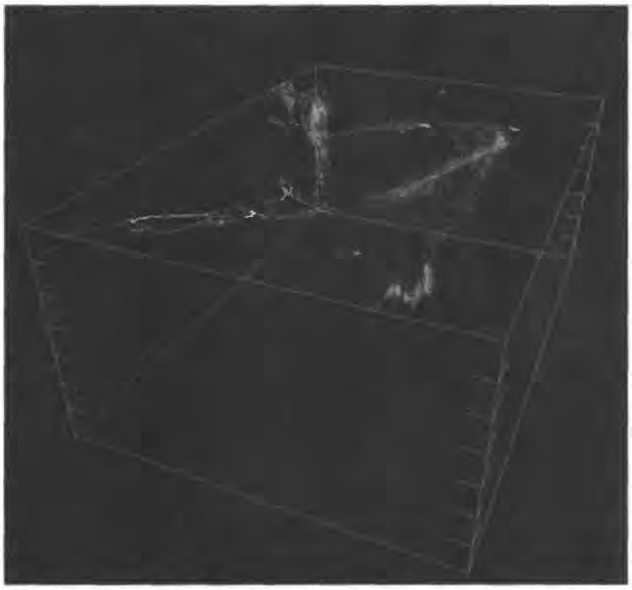

Figure 6. A VRML file of earthquake hypocenters beneath Tonga.

visualizations from data anywhere on the Internet. This frees the user from installing large numbers of plug-ins or downloading large JAVA applets that don't work. It also keeps the complex visualization software at a central site where it can be maintained and updated easily.

The SPARC system could be applied to the real time display of stream flow data. As data is downloaded from data loggers in the field, visualizations could be created and pushed to a display that has been custom described by the user. A second possible application takes advantage of SPARC's infrastructure for historical databases. Paleoclimate data can be included in SPARC along with their metadata, allowing users to construct maps in any area of the world, using a number of available proxies or models.

CONCLUSION

The current state of mainstream scientific visualization software falls short of being an ideal tool for use in digital mapping. Though polygons are drawn quickly and the images are impressive, the tools are lacking to create objects from standard earth science and Geographic Information System (GIS) formats in a way that geologists intuitively understand. The fallback position includes common GIS and remote sensing software in combination with existing visualization packages.

This is a situation common in many sciences. Visualization beyond two dimensions hasn't caught on as a day to day tool. The lack of agreement on Macintosh/Wintel graphics standards, the software industry's switch from workstation to PC economics, and little artistic training in the earth sciences can all be blamed. Even on the high end of the visualization food chain the software tools are painstakingly handcrafted and not readily customized for various scientific disciplines.

Choose tools carefully and be seduced by the increased understanding that you extract from your data, not the pretty pictures. Just because you can spin your field area in three-dimensions doesn't mean that you understand more of what's going on.

REFERENCES

CAVE References

The Electronic Visualization Laboratory — <http://www.evl.uic.edu/EVL/index.html>.

CAVE Guide — <http://www.evl.uic.edu/pape/CAVE/prog/CAVEGuide.html>.

Fakespace Systems Inc. — 809 Wellington St., N., Kitchener, ON, Canada, N2G 4J6, (519) 749-3339, <http://www.fakespacesystems.com>.

3D on the Web

Web3D Consortium — <http://www.web3d.org/>.

CosmoPlayer — Computer Associates International, Inc., One Computer Associates Plaza, Islandia, NY 11749, (631) 342-5224, <http://www.cosmosoftware.com/>.

3SpaceAssistant — Template Graphics Software, Inc., <http://www.tgs.com>.

Space Physics and Aeronomy Research Collaboratory (SPARC) — <http://intel.si.umich.edu/SPARC/>.

Brick of Bytes (BOB) — <http://www.arc.umn.edu/gvl-software/bob.html>.

Generic Scientific Visualization Packages

Iris Explorer — NAG LTD, Wilkinson House, Jordan Hill Road, OXFORD, OX2 8DR, UK, +44 1865 511245, <http://www.nag.com/Welcome_IEC.html>.

Advanced Visual Systems,Inc., 300 Fifth Avenue, Waltham, MA 02451, 781-890-4300, <http://www.avs.com/>.

IBM Open Data Explorer — <http://www.research.ibm.com/dx/>.

Stereo Hardware and Software

Stereo3D.com — <http://www.stereo3d.com/>.

Hardware

Silicon Graphics, Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043, (650) 960-1980, <http://www.sgi.com>.

Asus, Inc., 150 Li-Te Road, Peitou, Taipei, Taiwan 112 R.O.C., +886-2-2894-3447, <http://www.asus.com/>.

Elsa Erazor X — Elsa, Inc., 1630 Zanker Rd., San Jose, CA 95112, (408) 961-4600, <http://www.elsa.com/>.

Metadata Tips and Tricks

By Peter N. Schweitzer

U.S. Geological Survey
Mail Stop 918 National Center
Reston VA 20192
Telephone: (703) 648-6533
Fax: (703) 648-6560
e-mail: pschweitzer@usgs.gov

Metadata is the means by which we communicate to users of geologic map data what they need to know in order to understand and apply the data properly. A variety of resources are available to assist geologists in creating metadata that are consistent with the documentation provided for other scientific and ancillary data. This paper summarizes recent developments in those resources and encapsulates some useful guidelines by which the process of creating metadata can be managed effectively.

NEWS

Commercial offerings by RTSe-USA and ESRI now complement the freely-available tools developed by the user community. The Spatial Metadata Management System (SMMS) has recently been enhanced (http://www.rtseusa.com/), and the introduction of significant metadata management in ArcCatalog (http://www.esri.com/) promises to make the process more readily available to the GIS data producer. Recent changes in "Tkme" (http://geology.usgs.gov/tools/metadata/) support its use alongside GIS or in separate processing.

New utilities for processing metadata enable specific problems to be addressed more efficiently. When creating Enumerated_Domain sections to explain the meanings of abbreviated data values, the program "enum_dom" reexpresses a textual table of values and their definitions as metadata that can be pasted directly into Tkme. A similar program "src_info" carries out the same action for Source_Information sections, parsing simple bibliographic references into their component parts and writing the relevant metadata elements, which can then be inserted into the metadata document.

Web form version of the Enumerated_Domain helper:
<http://geology.usgs.gov/tools/metadata/tools/doc/ctc/edom.shtml>
Web form version of the Source_Information helper:
<http://geology.usgs.gov/tools/metadata/tools/doc/ctc/srcinfo.shtml>

For batch processing of metadata, the new facility "<tt>mq</tt>", an extension of Tcl/Tk, enables program code written in the Tool Command Language (Tcl) to read, modify, and rewrite metadata. Programming is required, but the Tcl language is simpler to use than the C-language code in which the programs mp and xtme are written.

Documentation for mq:
<http://geology.usgs.gov/tools/metadata/tools/doc/mq.html>

Recent improvements in mp, tkme, and related programs promise enhanced usability. mp now has the ability to generate HTML output as a series of "frequently-anticipated questions" (FAQ) using your metadata as the source of the answers. This method will help producers to review the metadata and will help users to understand the information more easily. Tkme now divides its window into two horizontally-arranged panes, with a small grip on the midline which can be used to adjust the relative sizes of each of the panes. Significant changes have been made to the program "err2html," whose purpose is to make the error reports generated by mp easier to understand. The new form of its output is tabular and ranks errors by severity, color-coding them and suppressing duplicate messages. New users may find this presentation more easy to interpret, so that problems can be fixed in order of their importance. These programs and their documentation can be obtained from
<http://geology.usgs.gov/tools/metadata/>

ADVICE

1. Ask for help

   Data producers at Federal, state, and local levels of government and in many non-governmental organizations have discovered that in the metadata creation process they have much in common. Numerous online resources are available to those who are experiencing difficulties, and it is important for new users to realize that other people are often happy to provide advice and assistance. See <http://geology.usgs.gov/tools/metadata/> for links to people and resources that can help.

2. Don't use DOCUMENT
   The old DOCUMENT aml was originally developed by EPA and USGS and subsequently supplied to ESRI for inclusion in ArcInfo version 7. This program had a number of flaws. It handles so much of the metadata so poorly that the metadata must be almost completely rewritten to be usable in the Clearinghouse. I have developed a web page to assist people in converting the output of DOCUMENT into metadata that is more appropriate. Please do not encourage anyone to use DOCUMENT, and do encourage them to seek help in rewriting metadata created using it.

   How to fix the output of DOCUMENT:
   <http://geology.usgs.gov/tools/metadata/tools/doc/document/>

3. Don't make too many files
   Metadata creators are often tempted by logic to generate a full record for each and every distributable data file that they might make available. While this approach is initially appealing, its eventual result is to wear down the person doing the documentation, with a concomitant loss of quality in the work. Concentrate on the data files that contain original scientific contributions, or files that have undergone significant processing that required careful judgements that other people would not necessarily make. Document ancillary data files as Source_Information in the Lineage, indicating each with a Source_Produced_Citation_Abbreviation in a Process_Step.

4. Don't make too few files
   It also does no good to try to describe too much information in a single record; the result is a record of undue complexity that is even more difficult for users to read than for the originators to maintain. Wherever sources, processing, or projection information vary among items in a data set, consider describing the components using separate metadata records.

5. Don't document ArcInfo attributes
   Some data attributes exist as a consequence of the GIS or other software used to create the data. Where these have not been infused with scientific information, they can safely be left undocumented because their meanings and their values can be readily inferred from the knowledge of the software used. So for ArcInfo data sets, don't document AREA, PERIMETER, LENGTH, FNODE#, TNODE#, LPOLY#, RPOLY#, cover#, or cover-ID unless you have taken the inadvisable step of storing important scientific information in one of these fields. This rule of thumb simplifies the presentation of metadata to the end-user as well as their creation and maintenance.

6. Errors are not equally important
   While it is a useful tool for checking the structure and format of metadata, it is not good to put too much faith in mp. Human review is the thing that really matters. mp can help, but isn't the sole arbiter of what is and what is not good metadata. Prioritize errors like this, from most serious (fix) to least serious (understand and let go):
   1. Indentation problems
   2. Unrecognized elements
   3. Misplaced elements
   4. Too many of some element
   5. Missing elements
   6. Empty elements
   7. Improper element values
   8. Warnings and upgrades

7. Leave some specific elements out if they cause trouble
   Some metadata elements are difficult to fill out and are so inconsistently understood in the community at large that it does not make sense to agonize over their values. Fill them in if you have appropriate information, but simply leave them out if not:
   Latitude_Resolution
   Longitude_Resolution
   Abscissa_Resolution
   Ordinate_Resolution

   Source elements, if left out, should be assumed to refer to the data set, publication, or report that is the subject of the metadata. These elements can be safely omitted if their values would be "this report":
   Entity_Type_Definition_Source
   Attribute_Definition_Source
   Enumerated_Domain_Value_Definition_Source

8. Review using FAQ-style output
   mp can now generate HTML in the form of a list of frequently-anticipated questions (FAQ) which is likely to be more familiar to many readers. This form of metadata can be used to facilitate the human review of meta-

data, especially by people who are not conversant with the metadata standard itself.

9. Use controlled keywords
With the proliferation of information available on the internet it is becoming increasingly important to provide keywords that come from widely-recognized thesauri such as Georef by AGI. Such keywords can be discovered by web search engines and are able to provide better conceptual associations among related data and reports than non-controlled keywords. Alternative user interfaces such as those based on pick-lists, can be developed if controlled keywords are chosen. I believe that interfaces more sophisticated than free-text search will become necessary in the future in order to find information effectively.

Illinois State Geological Survey Web-Based Resources: The Illinois Natural Resources Geospatial Data Clearinghouse and the ISGS Internal GIS Resources Web

By Sheena K. Beaverson and Robert J. Krumm

Illinois State Geological Survey
615 East Peabody Drive
Champaign, IL 61820
Telephone: (217) 244-9306
Fax: (217) 333-2830
e-mail: beavrsn@isgs.uiuc.edu

INTRODUCTION

The Illinois State Geological Survey (ISGS) in Champaign, IL currently hosts three major web-based information resources. These include the ISGS's main public web site <http://www.isgs.uiuc.edu>, the Illinois Natural Resources Geospatial Data Clearinghouse <http://www.isgs.uiuc.edu/nsdihome>, and the ISGS Staff Only intranet. This paper will focus on two ISGS web-based activities maintained and developed by the ISGS Geospatial Analysis and Modeling Section (GAMS) staff. These include the Clearinghouse project, and a sub-section of the Staff-Only intranet identified as the Internal GIS Resources Web.

CLEARINGHOUSE BACKGROUND

Overview

The Illinois Natural Resources Geospatial Data Clearinghouse serves as a gateway to Geographic Information Systems (GIS) data and imagery for Illinois. The project is a multi-agency effort by the Illinois Department of Natural Resources (DNR) Scientific Survey divisions and is associated with the Federal Geographic Data Committee's (FGDC) National Spatial Data Infrastructure (NSDI) clearinghouse. DNR project participants include the ISGS, Illinois Natural History Survey, Illinois State Water Survey, Illinois Waste Management and Research Center, Illinois State Museum, Office of Mines and Minerals, and Office of Realty and Environmental Planning (OREP). Available county and statewide data sets and documentation (metadata) include: geology, water resources, nature preserves, wildlife areas, environment, land cover, Digital Raster Graphic (DRG) files, surface elevation, Public Land Survey, political boundaries, roads, census information, and much more (Figure 1). Other features include a metadata generation tool, information about upcoming metadata workshops, a hotlist of other on-line DNR GIS data-related features, and a listing of DNR's aerial photography holdings.

Phase 1: Illinois FGDC Clearinghouse Node

The clearinghouse was brought on-line on July 1, 1997 and currently serves about 1,800 downloadable GIS data sets in ArcInfo export file format (Environmental Systems Research Institute, Inc), described by over 130 complete metadata documents (Nelson et al., 1998a, Nelson et al., 1998b). An additional 100 partial metadata files represent searchable entries from our working list. Data and metadata are accessible through keyword search functions and straightforward browse pages. The browse pages for statewide and county data are augmented with short abstracts, metadata, and GIF images that give a visual snapshot of each data layer. Users can conduct keyword searches of the metadata database either locally at the Illinois Clearinghouse or remotely from the national NSDI gateway (Nelson et al., 1998a, Nelson et al., 1998b).

Phase 2: United States Geological Survey (USGS) Digital Raster Graphic (DRG) Files for Illinois and FAQ-Style Metadata Available On-line

In April, 1999, DRG images of all USGS topographic quadrangle maps for Illinois were made available in a variety of projections and at the following scales: 1:250,000, 1:100,000, and 1:24,000 (Beaverson, 1999). DRG files are georeferenced images produced by scanning USGS topographic maps. This widely-used and recognized map format provides large and intermediate-scale, base map coverage essential for many mapping projects. These files can be selected via map indexes, by name, or by USGS index number, and are available in georeferenced TIFF format.

In early 2000, clearinghouse administrators began including a new metadata format in the browse areas of the web site. This format, generated with mp (Metadata Parser) (Schweitzer, 1999a), expresses metadata elements as answers to standard questions, and is casually referred to as FAQ-Style Metadata (Schweitzer, 1999b). Feedback from ISGS staff indicates that this easy-to-navigate format is a welcome addition to existing catalog options.

Web Statistics

The Clearinghouse project has been used extensively almost from the moment it went on-line. From July 1, 1997 to January 1, 2000, a period of 2.5 years, the site has had 1,453,044 hits by 90,478 individual external users, yielding an average 3,015 users per month. Over 142,100 data sets (roughly 66.5 gigabytes of data) were downloaded. In the year that the DRG files have been available free for download, 13,556 files have been downloaded, equaling 34.3 gigabytes of distributed data. From April 1 to September 31, 1999, an average of 675 DRG files were downloaded per month. This amount more than doubled, to 1,582 files per month in the next six months. This activity represents new data distribution, and these values exclude in-house access by ISGS staff. The ISGS uses WebTrends Enterprise Suite software to track and report Internet statistics (WebTrends Corporation). Although Internet statistics are somewhat uncertain, the numbers indicated herein suggest that the Illinois Natural Resources Geospatial Data Clearinghouse has received a great deal of attention and is providing convenient data access for the GIS community in Illinois.

ISGS INTERNAL GIS RESOURCES WEB

The ISGS Internal GIS Resources Web is an intranet resource providing information for ArcInfo- and ArcView-based GIS operations and web-based Oracle (Oracle Corporation) database interfaces. A detailed site index serves as the front page (Figure 2). Content has been written by members of the ISGS Geospatial Analysis and

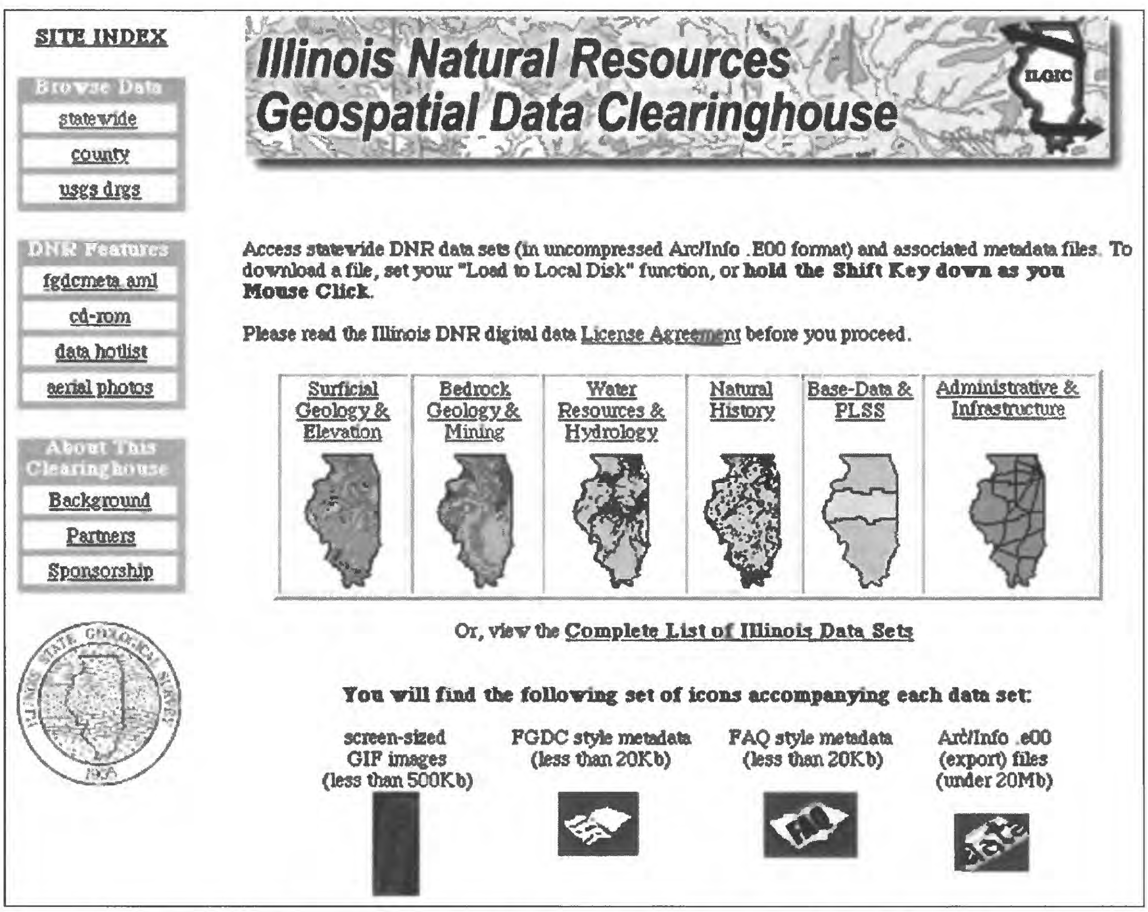

Figure 1. Illinois Natural Resources Geospatial Data Clearinghouse statewide data browse page.

Modeling Section (GAMS) over the past two and a half years. The 'Resources Web' provides staff with a common area to access a collection of Hyper Text Markup Language (HTML) documents in a password-protected area. The information can be accessed by any ISGS staff member from any computer connected to the Internet. New information is added monthly. The web pages present detailed information related to a wide variety of topics, including:

- ISGS database holdings, database design and maintenance,
- ISGS Oracle Database tables
- metadata creation tools and procedures,
- Clearinghouse upkeep and web statistics,
- plotting at the ISGS (user guides and administrative duties),
- GIS Educational Outreach class materials,
- in-house Atools and ArcView Projects,

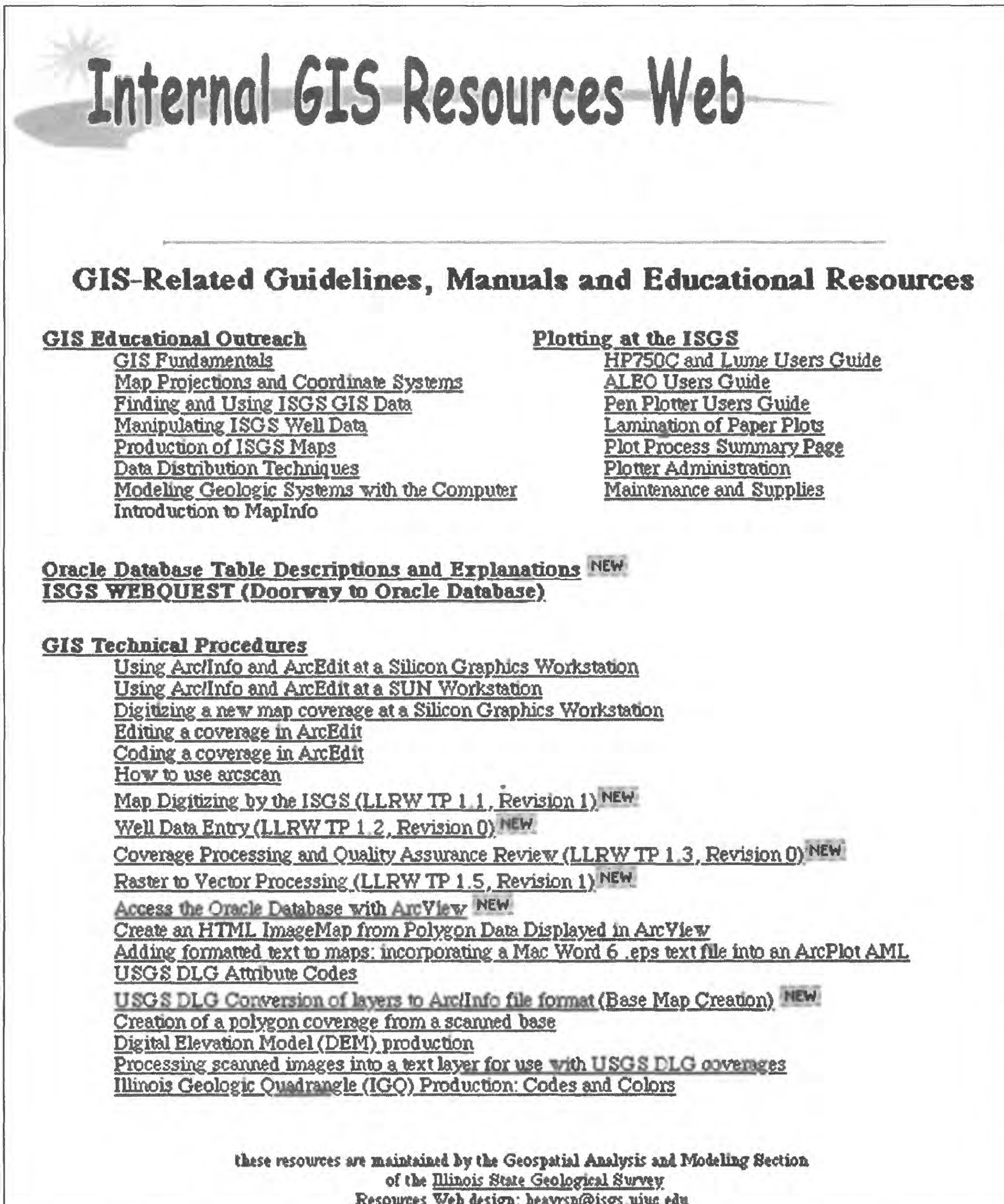

Figure 2. The ISGS GIS Resources Web main page (lower portion).

- cartographic resources and map templates,
- routine GIS technical procedures.

The ISGS has very limited intranet staff support and no formal intranet development policies. As a result, ISGS Staff-Only interfaces suffer from common intranet maladies, such as authoring bottlenecks, a lack of support from a formal resource center, non-standardized design, or a more simplified design as compared to funded Internet sites, and static content (Gantz, 2000; Nielson, 1999). Staff-Only web page design updates are sporadic and the link to the GIS Resources Web is somewhat difficult to find. As a result, individuals from other sections of the Survey who have questions typically contact a GIS-savvy staff member initially, rather than referring to the on-line reference materials. Nevertheless, members of our section save time and repetitive effort by guiding colleagues to the relevant on-line support materials. In the past year we have greatly expanded the content and begun to apply web usability principles. The Resources Web is gaining attention and positive feedback from our fellow ISGS employees.

CONTINUING EFFORTS

Phase 3: Illinois Digital Orthophoto Quadrangle (DOQ) Files Available On-line

In 1999, state and federal agencies with interests in Illinois entered into a joint funding agreement with the USGS to purchase the full set of Digital Orthophoto quarter Quadrangles (DOQs) for Illinois. DOQs are digital map layers made from aerial photographs that have been registered to map coordinates. Created from 1998/99 photography, these map coverages will be the most up-to-date, large-scale geographic base data available for Illinois. DOQs are well suited for many mapping projects, digital or otherwise. Over the next two years, the State of Illinois will receive one set of these data. External funding is being pursued by the ISGS to support the processing necessary to archive and distribute the 4,135 files. The ISGS plans to distribute compressed versions of the 1998/99 DOQ data files on-line, free for download, at the Illinois Natural Resources Geospatial Data Clearinghouse. The uncompressed data will be offered for sale on CD-ROMs.

We believe that access to the DOQ files will enable GIS and remote sensing professionals to more readily develop projects that foster sustainable use of natural resources. The DOQs will be a vital information resource to address the Illinois' changing land use demands. Thus, the application of DOQs to natural resource protection, mapping, and monitoring will likely yield significant economic impacts.

Addressing Web Usability Issues

Future revisions of the Geospatial Data Clearinghouse and the Internal GIS Resources Web will need to improve the ability of the user to quickly and intuitively access information. The book Designing Web Usability (Nielson, 1999) outlines and illustrates web design elements which improve web site usability. The following observations result from applying the principles put forward in that book. For the Clearinghouse, improvements in the content initially displayed to the user will be a high priority. Possible refinements include returning FAQ-style metadata as search results, simplifying introductory statements, review and revision of all metadata and Arc/Info data holdings, and migration away from a frames-based layout to individual web pages with Server Side Includes (SSI). SSI allow a web designer to insert repetitive information, like logos or navigation bars, from one master file into multiple HTML documents. For a brief description on implementing SSI, refer to the NCSA HTTPd Tutorials web site <http://hoohoo.ncsa.uiuc.edu/docs/tutorials> or this support page from a web service provider <http://www.infodial.net/support/ssi/index.htm>.

The Resources Web would benefit from targeted content expansions, a simplified front page interface, and a comprehensive review and update of older documents. A concentrated effort to increase development of the ISGS intranet would also result in enhanced reliance on sub-site reference materials. In the meantime, we will continue to make content additions when possible and strive to keep the navigational design as straightforward as possible.

ACKNOWLEDGEMENTS

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The Central Publications Group Map-On-Demand (MOD) System

By J. D. Hoffman

U.S. Geological Survey
Box 25046, MS 902
Denver Federal Center
Denver, CO 80225-0046
Telephone: (303) 236-2490
Fax: (303) 236-6287
e-mail: jhoffman@usgs.gov

INTRODUCTION

The U.S. Geological Survey (USGS) uses both conventional and digital methods for the compilation of geologic and other thematic maps. Increasing emphasis is being placed on totally digital compilation. The production system used by the Central Publications Group of the USGS was described by Lane and others (1999). Such maps have been and are continuing to be released via one or more of three methods: (1) printing maps on paper at a printing plant, (2) releasing maps online in PDF format, and (3) using the Maps-On-Demand (MOD) system. This paper discusses the third method.

Low-demand maps cost about as much to print as higher-demand maps. Because a large portion of USGS geologic maps are in the former category, conventional printing of such maps is often uneconomical. The Maps-On-Demand (MOD) system is designed to remedy this and other problems.

MOD GOALS

As the cost of printing via conventional press technology has become less affordable, the USGS MOD system has become more appealing. The system has seven distinct goals:

Print high-quality products. MOD maps are close to offset press print quality.

Allow for low-demand maps. The MOD system maintains no inventory.

Reduce production cost. The cost is about 25% of conventional offset press printing.

Decrease production delays. All production is "in-house" and is entirely digital.

Reproduce out-of-print maps. Maps are scanned and re-released via the MOD system.

Archive maps. Files are stored on CDR media.

Ensure that maps are never "out-of-print." The "inventory" is stored digitally.

ADVANTAGES AND DISADVANTAGES

The lower production cost results in higher customer costs. The price of a MOD map is $20 per sheet. In contrast, the cost for printed thematic maps is now $7 per sheet. We trust that customers will consider the price of a MOD product a fair trade for fast production or availability of an otherwise out-or-print map. In many cases, due to economic reasons, the MOD system allows for publishing maps that otherwise would not be published.

Because printing a map on a high-resolution plotter is quite slow, the MOD system has a low production capacity. Maps take typically from 15 to 30 minutes to plot.

MOD SYSTEM TOPOLOGY

The MOD system is powered by a Powerpage PostScript Raster Image Processor (RIP) bundled with the Postershop large-format printing system. The installation employs a client-server relationship (figure 1), with the server hosting both Apple Macintosh and Microsoft Windows-based PC's. The server software runs on a 400

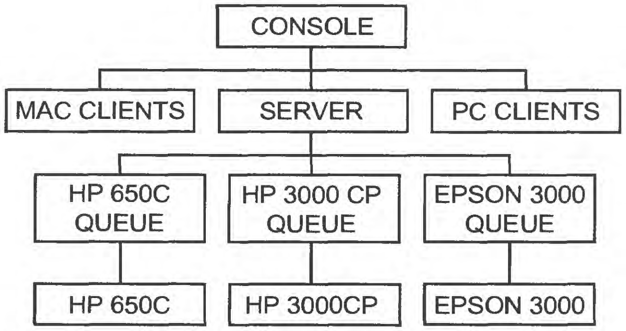

Figure 1. MOD system topology.

Mhz dual-processor Windows NT4-based server with 512 MB RAM and 27 GB of hard disk space. The RIP server software drives a Hewlett-Packard (HP) 3000CP plotter, an HP 650C plotter, and an Epson 3000 printer. Both Macintosh and Windows-based PC's are transparently served using easily configured clients.

SIGNIFICANT MOD FEATURES

The Postershop RIP server converts PostScipt and seven bit-mapped file types to plotter-native files. File rendition is extremely accurate. The maximum resolution of the HP 3000CP is 600 dpi. The maximum resolution of the Epson 3000 printer is 1,440 by 720 dpi. The HP 650C plotter, having a resolution of 300 dpi, is used for rough drafts. Input files size is for all intents and purposes unlimited; the system has successfully RIPed files approaching 1 GB.

A Postershop client installed on a Windows NT workstation is used for functions such as previewing an image to be RIPed, color adjustment of image files, creating and editing color profiles, tiling, and creating CD-ROM's of RIPed files for plotting and distribution.

MOD PRODUCTS

Geologic Investigation Maps (I-maps). I-maps present data and interpretations of lasting interest for scientific and technical audiences. MOD products are not generally released within this series; a few I-maps maps have been released as MOD I-maps.

Miscellaneous Field Studies Maps (MF-maps). MF-maps have the same content, quality, and review standards as I-maps but with a more limited scope, audience, or expected longevity. Also, urgency of release or lack of funds often require releasing a map in the MF series.

Open-File Reports (OFR). OFR maps are generally unedited preliminary maps intended to be superseded by formal publications.

Scans of out-of-print maps of any series.

DISTRIBUTION

Announcement of new MOD products is made through "New Publications of the U.S. Geological Survey" <http://pubs.usgs.gov/publications/> and the MOD web site at <http://rmmcweb.cr.usgs.gov/public/mod/>. This web site contains information about maps available though the MOD system and an order form. MOD maps are printed on an HP 3000CP plotter at 600 dpi resolution using UV-resistant inks and heavy-weight coated paper.

Other pertinent U.S. Geological Survey geologic map web sites are: <http://greenwood.cr.usgs.gov/>, <http://geology.er.usgs.gov/>, and <http://geology.wr.usgs.gov/>.

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Digital Geologic Map of Utah: A Method of Presentation

By Kent D. Brown[1], Grant C. Willis[1], Douglas A. Sprinkel[1], Denise Y. M. Laes[1], and Lehi F. Hintze[2]

[1]Utah Geological Survey
1594 W. North Temple
PO Box 146100
Salt Lake City, Utah 84114-6100
Telephone: (801) 537-3300
Fax: (801) 537-3400
e-mail: nrugs.kbrown@state.ut.us

[2]Brigham Young University
Provo, Utah 84602

INTRODUCTION

As Geographic Information System (GIS) technology becomes a primary tool for resource planning and research among federal, state, and local governments and educational institutions, the pressure to convert existing maps to GIS data is great. The 1:500,000-scale *Geologic Map of Utah* compiled by Lehi F. Hintze and published by the Utah Geological (and Mineral) Survey (UGS) in 1980 has served for twenty years as the most current geologic map of the entire state. Requests to have this map converted to a digital form have been more numerous than for any other UGS map.

The *Digital Geologic Map of Utah*, released on compact disc (figure 1) is, in general, identical to the 1980 published map; however, it contains some minor revisions. In addition, this digital release supercedes a digital version of the *Geological Map of Utah* distributed in 1995 by the geography department at Utah State University, Logan, Utah, which was considered temporary and incomplete.

The digital map is released on CD-ROM, and includes an attractive and easy to use autorun menu system for utilizing the presented data. The spatial data files that comprise the *Digital Geologic Map of Utah* are provided in both ArcInfo coverages and ArcView shapefiles, and as ArcInfo export files. The files are organized in several folders and subfolders. In addition to spatial data files, the map is provided in Portable Document Format (PDF) and as an ArcExplorer project for map users who do not have GIS software. Adobe Acrobat Reader and ArcExplorer from Environmental Systems Research Institute (ESRI), are freeware programs provided for viewing these files. Text, database, and image files are included to help the user view, evaluate, and utilize the spatial data. The metadata for each coverage or theme are in the respective subfolder that contains the spatial data. The projection of the geospatial data on the CD is Universal Transverse Mercator (UTM) zone 12, North American Datum 1927, and spheroid of Clarke 1866. The units are in meters. More than 400 megabytes of data are included on the CD.

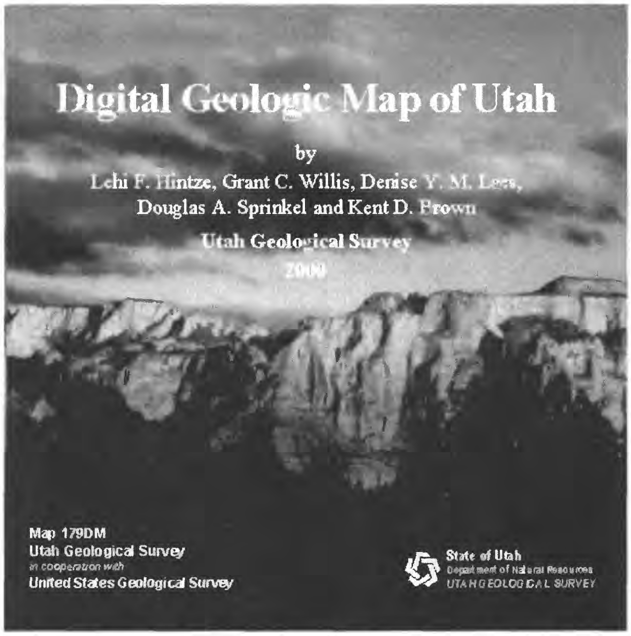

Figure 1. Printed cover for the Digital Geologic Map of Utah CD.

METHODS

The digital geologic map is a cooperative project of the UGS and the U.S. Geological Survey (USGS). The USGS contracted with Optronics Specialty Company, Inc. (19619 Prairie Street, Northridge, CA 91324) to scan, vectorize, and attribute the geologic map in ArcInfo format. Optronics scanned stable-base film positive separates of the original scribed geologic map provided by the UGS. Two separates were used: (1) geologic contacts and faults, and (2) open bodies of water that form boundaries of geologic units or polygons. Original copies of these separates are preserved in archives at the UGS.

Optronics scanned the separates on a high-resolution drum scanner. They then vectorized the resulting raster images using ArcScan and GRID. A published color copy of the geologic map was used as a guide to vectorizing. They compared the resulting line work with the sources by overlaying plots of the digital data and original maps on a light table. The edited vectors were then geographically referenced to UTM zone 12. ArcInfo software was used to produce polygon topology and assign geologic attributes to map features. Optronics determined the identity of map polygons for attributing by visual examination of the color polygons on the published map since many polygons do not have text annotations, and no annotation overlay was available in UGS archives.

The completed digital map was turned over to the USGS. They added line and symbol features such as volcanic cones, gilsonite veins, and igneous dikes by digitizing them from a paper map since no film positive of these layers was available for scanning.

The digital files were then turned over to the UGS for review and preparation for public release. The UGS carefully reviewed a color plot of the digital map to search for polygon and attribution errors. (The contract arrangement stated that Optronics would not attribute polygons for which they could not be sure of the proper geologic map unit identity or that might be in error on the original published map.) The UGS searched original sources to determine the proper identity of unknown or miscolored polygons.

The UGS then made a second round of reviews and corrections to the digital map. In addition, the UGS made a few selected revisions to improve the map from the 1980 version (see below). The UGS then prepared the digital map files, explanatory materials and files, and supporting documents for public release.

As part of the public release the UGS added the following disclaimers, which are used for our printed map publications and were adapted for the digital release.

"This digital map was produced from source mapping at 1:500,000 scale and is not intended for use at larger scales. Enlargement of parts of the map to larger scales may result in incorrect geographic placement or interpretation of geologic features."

"The Utah Geological Survey is not responsible for any unauthorized modification of this data. Any modification of this digital data must be clearly and prominently reported in printed and digital materials produced or distributed by the data modifier, and must not be attributed to, nor implied to be endorsed by, the Utah Geological Survey."

"The views and conclusions contained in this digital and printed map and report are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government."

MODIFICATIONS TO THE ORIGINAL MAP

The UGS, USGS, and Optronics made extensive effort to accurately reproduce the published 1980 geologic map. In general, the geologic map was not modified or updated to include new mapping or information acquired since 1980. However, during the course of reviewing the digital map it became apparent that some modifications or revisions were required before the digital map could be completed. For example, missing geologic contacts had to be added so polygons could be closed and attributed. Most problems were due to cartographic errors on the published map. We determined the proper or best solution for each revision by consulting the original source maps or other reliable newer maps. The UGS will maintain a file documenting these revisions.

These modifications are of the following types:

1. *Broken polygons (missing contacts or faults) on the published map.* Contacts or faults are missing in several places on the published map, resulting in two different adjacent map units that are not separated by a contact or fault (the colors of the units do differ on the published map). The contact or fault had to be added, otherwise the polygons could not be properly attributed.

2. *Mislabeled or miscolored polygons on the published map.* The reviews identified several mislabeled or miscolored polygons. We corrected these errors by checking against original source maps.

3. *Mislabeled contacts on the published map.* Some of the stratigraphic contacts on the published map are actually marker beds that are within rather than bound polygons, but were not labeled as such. For the digital map, these lines were changed to identify them as marker beds.

4. *Extra or unidentified polygons or contacts on the published map.* The published map has several polygons that are not labeled and are not identified by color as different map units. By checking source materials, we

determined that some are legitimate map units that were intended to be on the map, but that were missed during cartographic color preparation. These were properly identified and attributed. Others were found to be extra contacts or polygons that had been inadvertently added to the published map (since some parts of the map were compiled from more detailed sources, the compilers occasionally added extra lines). These were removed. Finally, polygons that bound perennial and intermittent bodies of water were identified and attributed for the digital map as "water" and "playa" respectively.

5. *Incorrect intersection of water boundaries and geologic contacts on the published map.* Open water bodies form the boundaries on one or more sides of many map polygons. In some cases, the contacts do not match properly with the water bodies on the published map. By contacting the persons who worked on the map, we learned that a newer base map with different water body boundaries was added to the 1980 map late in the compilation process, after many contacts were already drafted. Some of the contacts were revised to match the new base, but some were missed, resulting in contacts drafted within the water bodies, or that end before abutting the water boundaries. This was especially evident around the margins of Lake Powell. In these areas, the lines were modified to match the lake boundaries and to properly close polygons.

6. *Selected updates to the original map.* Much new mapping has been completed in Utah since the 1980 map was compiled from sources available at that time. In general, the UGS chose not to revise or update the digital map from the published map. However, though the changes in items 1 through 5 were made to correct cartographic (not geologic) problems, in some cases they may alter the geologic interpretation of the map. In addition, the UGS corrected identifications of a few map polygons that are incorrect on the published map based on the original sources. At the request of L. F. Hintze, the author of the 1980 map, the UGS removed one map unit from the Beaver Dam Mountains in the southwest corner of the map. This map unit does not exist, but was added to the 1980 map due to erroneous source data. Hintze felt that this error has the potential to cause considerable confusion for the map user and should be corrected. We also changed the labeling of the Glen Canyon Group formations (Wingate, Moenave, Kayenta, and Navajo Formations) and the Nugget Sandstone to reflect a Jurassic age rather than a Triassic/Jurassic age. This map unit is now labeled Jg rather than JTR. Though other updates were not made, the UGS does plan to update the digital and printed maps at an undetermined time in the future.

7. *Modification of state boundary for the digital map.* The boundary delineating the state of Utah was adjusted on the digital version of the geologic map to coincide spatially with the boundary of the 1988 U.S. Geological Survey 1:500,000-scale physiographic map of Utah. The 1988 base is used by the Utah Automated Geographic Reference Center (AGRC) as the standard base to create 1:500,000-scale spatial data.

COMPACT DISC CONTENTS

The *Digital Geologic Map of Utah* is the first formal UGS release of a geologic map in a GIS format. The CD contains many spatial data files (ArcInfo coverages and ArcView shapefiles) of Utah geology, including map units, faults, marker beds, igneous dikes, volcanic (basaltic) cinder cones, and gilsonite veins. Also included on the disc are PDF files of both the digital geologic map and the explanation sheet from the published map. These files include the stratigraphic columns and cross sections from different regions of Utah. Basic geographic spatial data are also included so the user can display the geologic data with familiar geographic themes such as county boundaries, 1:24,000 and 1:100,000-scale quadrangle map indexes, township and range and latitude and longitude grids, and roads using GIS software. Also included is a georeferenced digital raster graphic (DRG) of the topographic base map of Utah. Most of the geographic spatial data were obtained from the AGRC, the central GIS data clearinghouse for Utah state government agencies.

The spatial data, associated metadata, and image files are organized into four folders: (1) coverage, (2) e00, (3) images, and (4) shapes. These folders, except e00, are further organized into subfolders where the spatial data reside. The metadata files (*.met) of the geologic theme (or coverage) and most geographic themes are in the subfolders that contain their respective spatial data (figure 2).

Several programs located in the software folder can be installed on the user's computer to display data and document files. ArcExplorer 1.1 for Windows 95/98/NT/2000 enables users, who do not already have access to ArcInfo, ArcView, ArcExplorer, or other GIS software, to display ArcInfo coverages and ArcView shape files. An import utility file (Import71) is also included. This utility will convert ArcInfo export files "e00" into ArcInfo coverages.

Adobe Acrobat Reader 4.05 for Windows 95/98/NT/2000 is also included on the CD and is needed to view PDF documents.

The UGS provides ArcExplorer, the ArcExplorer Import Utility, and Acrobat Reader as a convenience and emphasizes that this does not imply a product endorsement. In addition, the UGS does not provide any support for this software. The user is provided with the name and contact information of the software companies for help or additional information regarding their products.

ACCESSING THE FILES

Much thought and effort went into the decision to use a new autorun menu system with this digital release. We wanted to create a CD product that would be easy to use for both the novice and experienced user. Users familiar with GIS software might simply copy the data files to their computer hard drive and go to work. However, since this digital map will appeal to those with no exposure to GIS, we have created an attractive and simple-to-use menu interface. The software we chose for the creation of the menu system is AutoPlay Menu Studio Professional. We found it is simple to use, very powerful, and capable of the operations we needed.

Insert the CD into the drive and in just a moment the autorun menu (figure 3) appears. The user is greeted with scenic pictures of Utah geology and an uncluttered menu to choose from.

These menu choices include:

- *Getting Started* - Offers simple instructions for use and a link to installing the ArcExplorer and Acrobat Reader software.
- *Explore CD* - Explores the CD folder structure.
- *About CD Contents* - Opens a PDF file describing the contents of the CD.
- *Browse Geologic Map* - View the geologic map in either PDF format or ArcExplorer project, where the user can perform limited searches. Also, view the explanation sheet as a PDF.
- *Documents* - Support documents in PDF format.
- *Other Resources* - WWW links to various sites, from ordering maps online at the UGS to downloading GIS data from the AGRC.

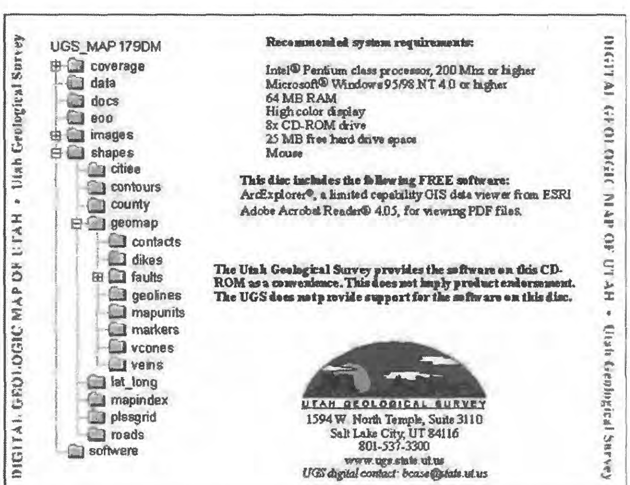

Figure 2. The back cover of the CD showing directory structure.

ACKNOWLEDGMENTS

The Digital Geologic Map of Utah was produced through a cooperative agreement between the Utah Geological Survey (UGS) and the U.S. Geological Survey (USGS). Grant Willis (UGS Geologic Mapping program manager) and Gary Raines (USGS Database and Information Analysis (DIA) project chief, Reno, Nevada) developed and directed this project. Ron Goodstein (Optronics Specialty Co. Inc., 19619 Prairie Street, Northridge, CA 91324) managed the scanning, topology, and attributing work on this project through contractual agreement with the USGS. Robert Miller, GIS analyst, directed the GIS work at the USGS. The UGS Economic Geology Program worked on the Utah Mineral Occurrences Database in a cooperative agreement with the USGS as "in-kind" financial support of this project. William F. Case, Chris Ditton, Jon K. King, Michael D. Hylland, and Jim Parker (UGS) reviewed the digital geologic map.

We gratefully acknowledge the efforts of many faculty and students at Utah State University and of Janine Jarva of the UGS (now at AGRC) who worked on the earlier version of the digital map.

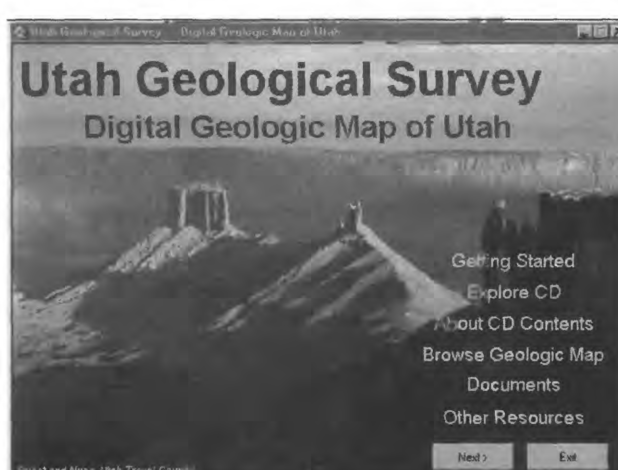

Figure 3. The initial screen of the CD menu system.

ACQUIRING DIGITAL AND PRINTED PRODUCTS FROM THE UTAH GEOLOGICAL SURVEY

Contact the Natural Resources Map & Bookstore at:

1594 W. North Temple
P.O. Box 146100
Salt Lake City, Utah 84114-6100

Bookstore phone:	toll free 888-UTAH MAP (888-882-4627) 801-537-3320
Web address:	http://www.maps.state.ut.us
E-mail address:	nrugs.geostore@state.ut.us
UGS receptionist:	801-537-3300
UGS fax:	801-537-3400

Development and Compilation of Comprehensive Geospatial Data, Coastal Alabama, for Integration into the Minerals Management Service's Gulf-Wide Information System (G-WIS)

By April Lafferty and Berry H. (Nick) Tew

Geological Survey of Alabama
P.O. Box 869999
Tuscaloosa, AL 35486-6999
Telephone: (205) 349-2852
Fax: (205) 349-2861
e-mail: alafferty@gsa.state.al.us, ntew@gsa.state.al.us

BACKGROUND

The Alabama Coastal area is a region of dynamic and complex coastal and near shore ecosystems and natural environments where anthropogenic factors and pressures have become increasingly significant. Parts of coastal Alabama have been extensively affected by rapid growth and development associated with urban and residential expansion, a flourishing tourism/resort industry along Gulf of Mexico beaches, and both onshore and offshore oil and gas exploration. Owing to the complexity and diversity of issues and problems related to the coastal area, its environmental sensitivity, and its importance to Alabama's economic and social development, the Geological Survey of Alabama (GSA) has conducted numerous scientific investigations in the area, many of which have led to published reports of findings. In addition, GSA is presently involved in various ongoing geological, hydrogeological, environmental, biological and energy-related studies directed toward collecting, compiling, assessing, and managing data from coastal and offshore Alabama. Geographic Information System (GIS) technology and the development and use of digital geospatial data have become increasingly important at GSA in recent years and are now routinely included as elements in nearly all research efforts at the agency. GSA has realized the benefits of GIS technology for data management and analysis and as a decision-support tool, and has made a strong commitment to an ongoing program of data development and management, as well as documentation of these data with Federal Geographic Data Committee (FGDC) compliant metadata records.

In 1995, the GSA participated in mapping shoreline types for use in oil spill contingency planning during the initial phases of the development of the U.S. Department of the Interior, Minerals Management Service (MMS), Gulf of Mexico Region, Gulf-wide Information System (G-WIS). The G-WIS was designed to provide a comprehensive database for oil spill contingency planning and environmental analysis in the Gulf of Mexico. One objective of the G-WIS was to have regional consistency of data across state boundaries and offshore (Louisiana State University, et. al., 1996).

Limited financial resources in 1995 restricted data development and GIS compilation to identification and attribution of shoreline types, biologic data, and other limited data sets. Other important data layers such as oil and gas infrastructure, roads, hydrography, and land use/land cover were still needed to complete the G-WIS. The GSA began gathering and developing the additional data layers in late 1999. This data development program targeted the Alabama coastal counties (Mobile and Baldwin) and the offshore Alabama state waters area. The successful completion of this project will result in a more comprehensive GIS database for the Alabama coastal area that will enhance the ability of MMS, state resource agencies, and others to make informed decisions regarding the development of Alabama's coastal and offshore resources in a safe, environmentally prudent manner.

PROJECT OBJECTIVES

The primary objectives of this project were as follows: (1) Identify the best available data/information resources for development or update of the data layers to be compiled; (2) Modify, compile, and integrate identified existing data into G-WIS specified digital format; (3) Develop new data sets, particularly up-to-date land use/land cover, as appropriate; and (4) Make all data developed as part of this project available to MMS, industry, and the public in various electronic formats and via various delivery mechanisms.

To address these objectives, the GSA undertook a coordinated effort to identify, acquire, update and convert existing data sets into the G-WIS standard format. The GSA coordinated closely with other state resource agencies, such as the State Oil and Gas Board of Alabama (OGB) and Alabama Department of Conservation and Natural Resources (ADCNR) to locate, enhance, or develop the needed data. The GSA identified several datasets such as land use/land cover, socioeconomic data and place names that did not exist and needed to be created.

DATA DEVELOPMENT AND COMPILATION

This data development program targeted the Alabama coastal counties (Mobile and Baldwin) and the offshore Alabama state waters area. All data sets were compiled in accordance with the G-WIS Database Specification Manual (Louisiana State University and others, 1996) and the Gulf-Wide Information System Data Dictionary. The G-WIS is comprised of ArcInfo coverages and associated lookup tables (Figure 1). These lookup tables included contact and source information for all socioeconomic and managed lands data and seasonality, breeding, and activity data for all biologic data layers. All data sets were documented with metadata developed according to the FGDC Content Standard for Digital Geospatial Metadata.

Brief Overview of G-WIS Data Sets

Recent vintage (1995-1996) LandSat Thematic Mapper imagery (35m resolution) was classified to determine land use/land cover. This classification was based on a modified Anderson classification scheme developed at the U.S. Geological Survey (USGS). Fieldwork included mapping land use 'seed' sites onto enlarged paper copies of the imagery to serve as a check for the classification. Each 'seed' site was an area usually in excess of five acres that exhibited one of the land use types, such as planted pine forest, deciduous forested wetland, shrub/scrub, high density urban, etc. The imagery was then classified using ERDAS IMAGINE software. The classified image was spot checked against the seed sites to determine the accuracy of the classification. Rather than create an ArcInfo coverage (vector GIS layer) that would have caused unnecessary generalization of the data, the image was retained as a classified raster image that can be viewed and queried in various GIS packages. Previous attempts to convert raster to a vector images, such as a standard ArcInfo coverage, has yielded very generalized results that may not reflect accurately the original classification.

A coverage of all roads in the coastal counties (ROADS) based on the USGS Digital Line Graphs (DLGs) was created and attributed to match the G-WIS format of primary routes, secondary routes, and other roads. A point coverage of all place names on USGS topographic maps was created from the USGS Geographic Names Information System (GNIS). This data layer was created by querying the GNIS for all place names in Alabama, dumping the data to a text file, and then generating a point coverage in ArcInfo.

A state oil and gas lease block boundary coverage (LEAS_ST) was created from a Chart of Submerged State Lands produced by the ADCNR. The state/federal boundary was digitized to obtain an accurate representation of this boundary. A topographic map index coverage (INDEX) was created to include all USGS 7.5-minute topographic maps (scale 1:24,000) in Mobile and Baldwin Counties.

A managed lands coverage (MGT) of public lands managed by state and federal agencies was created from available shapefiles from the DCNR State Lands Division, the USGS, and the United States Forest Service. The shapefiles were obtained in a variety of projections and generated at a variety of scales. The GSA converted all shapefiles to ArcInfo coverages and projected them all to a common projection. Each newly generated coverage was reviewed and the coverages were appended into a managed lands coverage. Because many of the managed lands boundaries are unavailable, it is unlikely that this coverage includes all managed lands in the coastal counties, but it does include a significant portion of the available data.

Stream (STREAMS) and lakes (LAKES) coverages containing all linear and polygonal water-related features were created from USGS DLGs. All water bodies in the coverage that were labeled on the USGS 1:100,000 topographic maps were attributed with the name listed on the map. The human-use features point coverage (SOCECON) and associated attribute (SOC_DATA) and source (SOURCES) information was updated to include additional features (e.g., gas wells, gas platforms, factories, artificial reefs, etc.).

The biologic data table (BIORES) and species table (SPECIES) generated by another entity was updated to remove erroneous information. While reviewing the biologic data with ADCNR Marine Resources Division, two mammal species present off the coast of Alabama, the Bottlenose dolphin and the West Indian manatee, were identified as absent from the database. Although no sys-

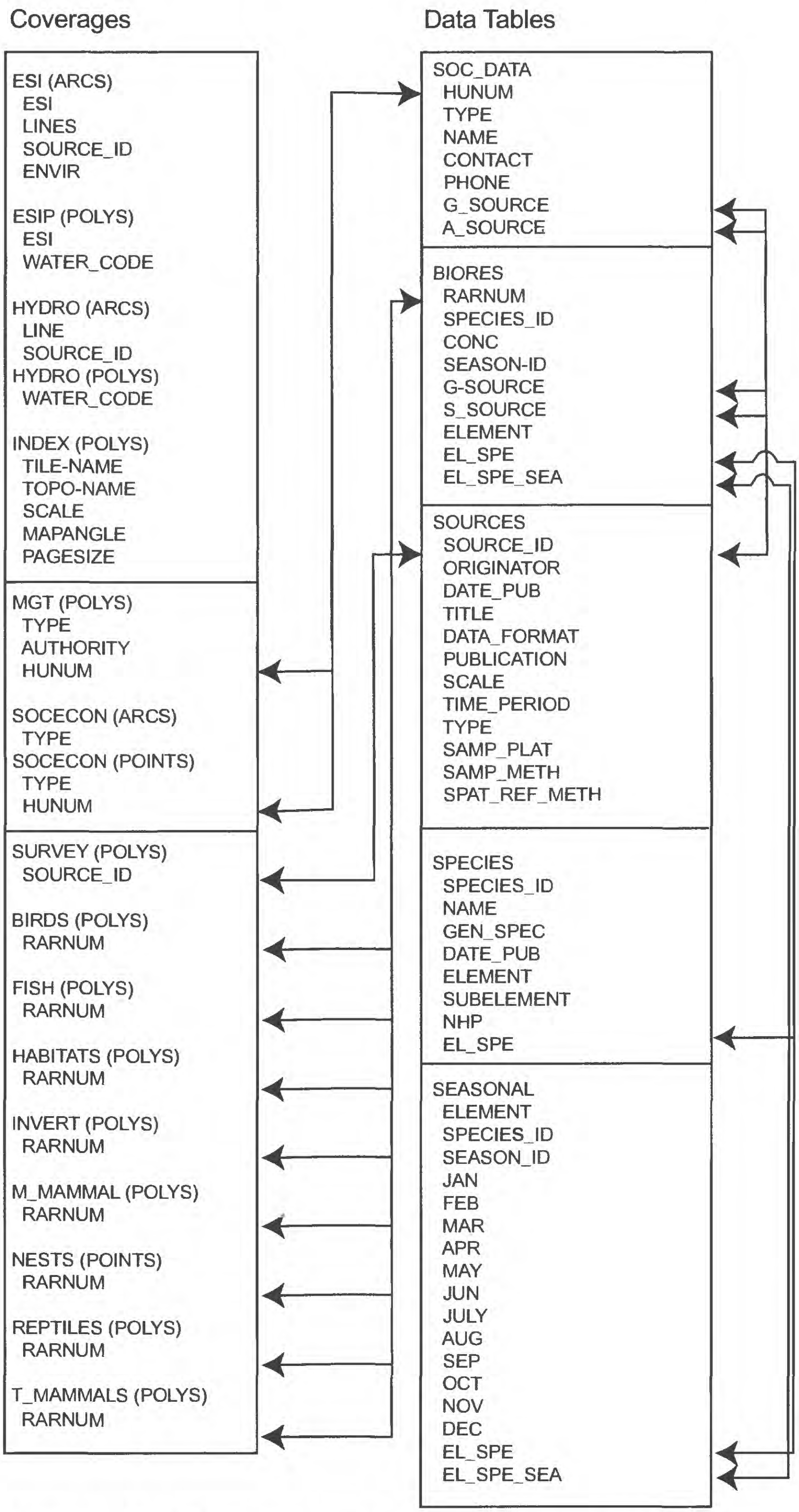

Figure 1. G-WIS Database Entity Relationship Diagram (modified from MMS, 1999).

tematic study of these marine mammals has been completed, some systematic and anecdotal information is available. A marine mammal (M_MAMMAL) polygon coverage to indicate marine mammal presence in the Alabama waters was created and associated seasonal, biores, species, and source tables were updated to include the marine mammal data. Data for these marine mammals were entered into the database in a generic fashion to include a presence in all Alabama coastal waters.

PLANS FOR THE ALABAMA G-WIS DATASETS

The G-WIS contains information that is applicable not only to oil spill contingency planning but also to coastal public access planning, urban and land use planning, and natural emergency contingency planning, among others. Therefore, the MMS has made all data available as shapefiles and DBF Tables via a CD-ROM. In late 2000, the GSA plans to provide, on their website <http://www.gsa.state.al.us>, many of the coverages generated during this project available via an interactive map. Additionally, the GSA will post much of the data on its clearinghouse, available (at the same URL) for download.

REFERENCES

Louisiana State University, Center for Coastal, Energy, and Environmental Resources; United States Minerals Management Service; Research Planning, Inc.; and Environmental Systems Research Institute, Inc., 1996, Gulf-wide Information System (G-WIS) Database Specifications Manual: Version 2.1, 72 p.

Minerals Management Service, 1999, Gulf-Wide Information System (G-WIS) CD-ROM: MMS 200-027.

Proposal for Authorship and Citation Guidelines for Geologic Data Sets and Map Images in the Era of Digital Publication

By Stephen M. Richard

Arizona Geological Survey
416 W. Congress #100
Tucson, AZ 85701
Telephone: (520) 770-3500
FAX: (520) 770-3505
e-mail: richard_steve@pop.state.az.us

INTRODUCTION

As more and more geologic data are released in digital form, new conventions for citation of sources are becoming necessary. Existing proposals for authorship guidelines have laid groundwork for new conventions (U.S. Geological Survey, 1995; Berquist, 1999). This proposal is an effort to formalize these conventions by clearly defining all terms and considering all paths between data collection and publication.

Geologic data originate as a set of observations made at particular spatial locations (field observations). Samples collected at particular locations may be subjected to more detailed analysis to supplement the field observations. These observations are interpreted to define the map units and locate boundaries that together constitute a geologic map. The geologic map constructed from these observations represents a model of some aspect of the earth in the area depicted. Depending on the nature of the geology, the experience of the geologist, and the goal of the data collection, the model that a geologic map represents may be as simple as the distribution of materials on the earth's surface, or as complex as the 3-dimensional structure of polydeformed metamorphic rocks. The person or persons who develop a model of a particular region of the earth by collecting observations, defining map units, and locating and interpreting faults and boundaries between the map units are the original authors of geologic data.

DEFINITIONS

A **Geologic data set** is a collection of map unit definitions, interpretations of the nature of the boundaries between the map units, locations of faults and boundaries between the map units defined, and descriptions (quantitative and qualitative) of the internal structure of the map units. Data set as used here is independent of the format of the data—it may be digital or analog. Geologic data sets built by the traditional geologic mapping approach outlined above typically start out as a collection of paper 'field sheets' and notes, which are assembled mechanically into geologic map images that represent the author's 'earth model' and data set. The geologic map may be accompanied by a report that adds information to the data set in the form of tabulated data, descriptive text and figures, and supplemental geologic map images. Using modern technology, it is now possible to build a data set directly into a digital database. A geologic data set is defined by:

1) The conceptual model that defines the kinds of things that may be represented, how these things are related to each other, and rules that determine valid data sets.
2) The region (area or volume) that is represented by the data set, referred to as its extent.
3) The particular map units, boundary locations and interpretations, and quantitative or qualitative descriptions included in the data set.

The conceptual model is the data collector's abstraction of the geologic framework. Conceptual models evolve over time, both in the development of a single data set, and with the development of the science of geology. The concepts at the disposal of the data collector determine the sort of things that are observed. Maps of the Franciscan complex produced before the development of ideas about melange and accretionary wedges are quite different from maps produced after those concepts were developed. Different conceptual models might be applied to the same outcrop area depending on the interests of the data collector. Consider the different approaches used to map surficial deposits, alteration zones, or bedrock geology.

The science of geology is founded on a set of rules that reflect our understanding of the Earth. These include the establishment of relative age based on crosscutting relationships, and the laws of original horizontality and superposition for sedimentary rocks. The conceptual model for a geologic data set includes these widely accepted rules as well as more local rules based on understanding of the regional geology, and rules developed for the particular map area in the course of data collection. The geometry and topology of map unit boundaries and faults imply a geologic history based on these rules. A geologic data set is valid if the geologic history it implies is internally consistent, and if the material at any location in the modeled area or volume belongs to at least one map unit.

There are many approaches to collecting observations and developing an 'earth model' to build a geologic data set. The traditional, stereotypical approach is to take a paper topographic map or air photo, and walk around an area making observations, building a model of the geology as it is drawn on the base map. Another approach to developing an earth model might include studying core and cuttings from wells, well logs, and seismic lines, and drawing cross sections or structure maps on a particular boundary. Gravity and magnetic data may be collected and interpreted in terms of a set of 2 or 3-dimensional bodies of rock with particular physical properties. Remotely sensed data of a variety of sorts may be interpreted to define map units on a planetary surface and build an Earth (or Venus, or Mars...) model. All of these processes are analogous.

A **single data set** is based on a single data source, typically a mapping project under a single authorship. A **compiled data set** integrates information from multiple sources. The author of a compilation evaluates all the included data, and must resolve inconsistencies in the earth model(s) underlying the various sources. These discrepancies might include different locations of rock body boundaries, different definitions of mapping units, different levels of structural detail, different base maps, and emphasis on rocks of different ages or types (e.g. bedrock vs. surficial). Compilation may also require generalization of linework on source maps to be appropriate to the scale of the compilation being produced. A **data anthology** is a collection of data sets that have been aggregated in a single structure, but may have internal inconsistencies. A geologic data anthology might include compiled data sets with different compilers and data sources, and data sets with overlapping or coincident extents.

A **geologic map image** is a representation of a geologic data set for an area. The map image is defined by the map area extent, the map projection, a specification of the surface represented by the map, the geologic data used, the choice of symbols for geologic features, and the cultural and physiographic base map. The path from a geologic data set to a geologic map image requires selecting symbols to represent the distribution of the map units, the location and type of map unit boundaries and faults, and the location and relevant data for point observations (orientation measurements). These symbols are placed on a base map that represents the map area by means of a projection and some elevation model to represent topography on the mapped surface. The base map provides a visual reference frame to depict the spatial relationships between geologic features, and a means of physically locating the features depicted. Design of the base map is an important aspect of cartography. This definition of a map image makes no distinction between a standard geologic map (map surface = earth surface), a mine-level map (map surface = horizontal plane), or a cross section (map surface = vertical plane along section line).

A geologic map image may be published in a traditional paper form or as a digital file. For a traditional map printed on paper, a limited number of identical copies of the map exist, and modification of the map requires significant duplication of the effort made to produce the original map. Citations for such maps follow the established conventions (author, date, title, map series, publisher, scale, media). This map image is fixed by the design on the printing plates, and every copy of the map will be identical. A **digital geologic map** is a geologic map image published as a digital file that allows the map image to be viewed on a dynamic display (computer monitor, computer projection system, etc....) or reproduced on paper or other physical media (film, T-shirts...) by the user. Because the image is in a digital file, it may be printed in whole or in part, and may be printed at different scales. Depending on the file format, users may be able to modify elements of the cartography—change colors or symbols, hide some of the symbols, or even add new base map elements. A citation to a digital geologic map refers to the particular map image in the original digital file. The image may be printed or displayed at different scales, in whole or in part, with different colors or other cartographic modifications. If the image is modified to change the geologic interpretation represented, then a new map has been produced.

A **digital geologic data set** represents a geologic data set in a georeferenced form using a set of computer files. A digital geologic data set is defined by:

a) The conceptual model that is the basis for the geologic data set (see discussion above).
b) A logical data schema that is a mapping of the conceptual model underlying the geologic data set to data structures that can be represented by an automated system (e.g., relational tables).
c) An implementation schema that defines the organization of data into files, the detailed structure of the files, and the representation of data in the files. The file format dictates the software and hardware systems that are compatible with the data.

d) A projection that describes how the geographic location of features is specified.
e) The data instances contained in the files.
f) A set of definitions that specify the meaning of attributes applied to included data instances.

A citation to a digital data set refers to the particular combination of these components. If any of the components are modified, a new data set is created. Modifications might include mapping the logical schema from a relational data model to an object-oriented data model, importing the data into a software system that requires a different file format, changing the projection of the data, adding, deleting, or updating data instances, or updating aspects of the data classification.

A **geoscience database system** is a digital geologic data anthology along with tools for entering, updating, tracking, querying, and visualizing the data. Data visualizations commonly take the form of geologic maps, which are analogous to tabular reports generated from standard non-spatial databases. Other types of 'reports' that are useful include text summaries of rock unit definitions, and stereonet plots of orientation data from a particular area or map unit. The database may include tools for generating standard map visualizations from the data, based on an automated-cartography procedure, and standard map templates and symbol sets.

SUGGESTED AUTHORSHIP AND CITATION CONVENTIONS

A geologic data set may be published as geologic map images and text or as a digital data set. They are different representations of the same thing—an underlying collection of observations with an associated earth model. A citation to a geologic data set, whether represented as a map image or a digital data set, refers first and foremost to the underlying collection of observations and the associated earth model. In order for the citation to be meaningful as documentation, all of the components of the cited data set, as defined above, must be immutable. If deemed appropriate by mutual agreement of the authors, authorship may be expanded to include roles in addition to the intellectual origin of the geologic data set. For a map image, the authorship may be expanded to recognize contributions to the cartography. For digital data sets, the authorship may be expanded to recognize contributions to data editing and quality assurance if data conversion is required. Authorship recognizes essential contributions to the intellectual origin and accurate representation of a geologic data set.

In order to recognize the different sorts of geologic data sets, several terms are defined that should be included in document titles to clarify the nature of the represented data set.

Geologic map of...	A single or compiled data set represented as a map image
Digital representation of...	A digital map image in a vector file format, produced by data conversion from a physical orig inal, and meant to reproduce the geologic data set
Spatial data for...	A single or compiled data set represented as digital geologic data
Anthology	A geologic data anthology
Scan	A digital geologic map image in a raster file format that can be displayed to duplicate a map image on physical media.
View	A digital geologic map image produced by a database query and automated cartographic pro cedures from a digital geologic data set or database.

Digital data sets and map images are subject to more frequent modification than their predecessor representations on paper. These modifications may include update by their originators, editing by other authors, and aggregation with other data. A compound form of citation is necessary that recognizes both the originator and the modifier(s) of digital geologic data sets. The compound citation first recognizes the current form of the data set representation, followed by a relation term to a source data set.

"**adapted from...**" is used to indicate derivation of a data set or a map image from a published map image when the product (data set or image) is meant to represent the same geologic data set as the original, but the map extent, cartographic design, or base map may be different.

"**derived from...**" is used to indicate derivation of a map image from a GIS spatial data set or database. Implies that the location of points and lines is equivalent to that in the database, and all polygons having the same classification in the database are symbolized with the same graphical element on the map image.

"**based on...**" is used to indicate derivation of a data set or map image from a published map image, but that minor changes have been made to the geologic data set. Derivative maps generated by tracing a map on physical media are always considered based on because the location of lines and points can not be reproduced exactly.

Other contributions may be prominently recognized in the title block of the map, but not included in the formal citation. Examples might include "Includes mapping by ..."

for a compiled map, or "Data editing and conversion by..." for digital geologic data.

The process of constructing a digital geologic map image includes:

1) Development of the underlying geologic data set: the geologic classification, location, and description of geologic features.
2) Conversion to digital form if necessary.
3) Selection of features to include in the map image.
4) Cartographic design of map image, including base map design and feature symbolization.

The data conversion (step 2) is in many cases functionally equivalent to the role previously played by the drafting person, in which case acknowledgment is not necessary. Step 2 may include significant editing and error correction if it is done by a geologist, in which case the input should be recognized in printing on the map image ("Data conversion and editing by..."), or by inclusion in authorship (included in the map citation). Step 4 may be equivalent to the role of a technician if the cartography of a published map is to be reproduced as nearly as possible in a digital form, in which case acknowledgment is not necessary. New cartographic design involves significant input and understanding of the map content, and should be either acknowledged in printing on the map image ("Cartographic design by ...."), or be recognized by inclusion in the map authorship (included in the map citation).

Three kinds of authorship must be tracked for a digital geologic data set:

1) Data schema authorship for the design and implementation of the data schema for the database.
2) Data entry authorship for entry of information in the database, and verification of the accuracy of the data entered.
3) Intellectual authorship for origination of the actual geologic data that are used to populate the data set.

Database schema design and implementation precede and are independent of the data entry phase, and should be documented in one or more stand-alone publications attributed to the appropriate author(s).

Data entry typically involves a technician, who does the typing and digitizing, and an editor, who is responsible for the accuracy of the product. One or several persons may play these roles. For a **single digital data set** based on a single published or unpublished source (map or field notes and field sheets), the editing role simply involves comparison of the original data against the location and attribution of features in the data set. Neither the digitizing nor the editing role requires intellectual input of a specialized geologic nature. Data entry technicians should be identified and acknowledged. The data set editor could be listed as an author in the editor role. For a **compiled digital data set** that integrates information from multiple sources, the editor role requires reconciliation of sources at the boundaries between the maps, and correlation of the 'earth models' underlying the various source maps. In this case, the editor role is analogous to the 'compiler' of a map image based on various sources.

MAP IMAGE EXAMPLES

Each numbered case below discusses a particular set of circumstances for a published printed or electronic map image. Example citations to Virginia maps are based on examples in Berquist (1999), and are included to show how they fit into the scheme proposed here. As a rule, a citation for any geologic map image should clearly define the source of the underlying geologic data set, the display scale used for designing the cartographic composition, the publisher of the map, and the medium used to transport the image. For maps on physical media, this is typically sheet(s) of paper, and possibly an accompanying text. For digital images, the citation must specify the number and format of the file(s) that contain the map image and any associated text. The physical media (floppy disks, CDROM, DVD....) that contain the files is not essential, since the files can be copied between media, or may be transferred directly across a network.

1. **Map image on a physical medium that represents a single data set.** A fixed quantity of identical copies is produced in a single press run (traditional printed paper map). The map image is an original publication, produced under the direction of, or by, the same authorship as the geologic data set the map represents. The mechanics of producing the map image that is printed may be described in the map surround, and acknowledgement for persons contributing to the map production should be included as appropriate.

   Richard, S.M., and Spencer, J.E., 1997, Geologic Map of the North Butte Area, Central Arizona: Tucson, Arizona Geological Survey Open-File Report 97-4, 1 sheet, 15 pages, scale 1:24,000.

2. **Map image on a physical medium that represents a compiled data set**. A fixed quantity of identical copies is produced in a single press run (traditional printed paper map). The map image is an original publication, produced under the direction of, or by, the same authorship as the geologic data set the map represents. The mechanics of producing the map image that is printed may be described in the map surround, and acknowledgement for persons contributing to the map production should be included as appropriate. The map surround or accompanying text must include citations to sources of data.

   Richard, S.M., and Spencer, J.E., 1998, Compilation of geology of the Ray-Superior area, Pinal County, Arizona: Tucson, Arizona Geological Survey Open-File Report 98-13, 1 sheet, 35 pages, scale 1:24000.

Spencer, J.E., compiler, 1995, Geologic Map of the Little Horn Mountains 30' by 60' Quadrangle, southwestern Arizona: Tucson, Arizona Geological Survey Open-File Report 95-1, 1 sheet, 10 pages, scale 1:100,000.

3. **Map image with single authorship, represented as a picture in a raster-format file.** The map image is identical to the source material that was scanned, within limits of scanning and display accuracy. Citation appends "[scan]" to the map title; the publisher and series identification remain the same; the medium description specifies the file format; and the scale is labeled 'map layout scale', which is the scale at which the original cartographic design was done, because the digital image may be displayed at widely-varying scales. A citation to such a map image for a map also published on a physical medium is specifically to the digital version of the map image, distinct from the original published version of the map. If the geologic data set represented by the map is being cited, the original map publication should be cited using the format of case one or two above. If the raster image is the only published form of the geologic map image, then the geologic data set it represents is always cited in this format.

Richard, S.M., and Spencer, J.E., 1997, Geologic Map of the North Butte Area, Central Arizona [scan]: Tucson, Arizona Geological Survey Open-File Report 97-4, 1 Adobe Acrobat (pdf) file, map layout scale 1:24000.

Doe, John, 1997, Geologic map of the Walker Quadrangle, Virginia [scan]: Richmond, Virginia Division of Mineral Resources Manuscript Map 97-3, 1 tagged image format (tif) file, map layout scale 1:24,000.

4. **Map image is a digital, vector-format representation of a map published on physical medium.** The map image produced is not identical to the original source, but it represents the same geologic data set. No digital geologic data set representing the same geologic data set is published. The process of producing vector data to represent the map requires tracing all lines and classifying the graphical objects produced (points, lines and polygons) to match the original. This is fundamentally different from scanning the map because of errors inherent in tracing, and the possibility of classification errors. In addition, the colors and symbols are unlikely to match the original exactly, and may be modified on purpose or by necessity. If the author of the original, physical map is not involved with production of the digital map image, the title of the digital map is constructed as "Digital representation of..." followed by the original title. A citation to such a map is specifically to the particular digital version of the map image, distinct from the original published version of the map. Thus, authorship of the digital representation indicates responsibility for the accuracy of the data conversion process. If the geologic data set represented by the map is being cited, the original map publication should be cited using the format of case one or two above. The medium description in the citation for a digital map indicates the file format of the digital representation. A scale is not necessary for the digital representation because it is specified in the citation to the published source.

Motiwala, P., 1998, Digital representation of Geologic Map of the North Butte Area, Central Arizona: Tucson, Arizona Geological Survey DI-999, 2 Adobe Acrobat files. Adapted from Richard, S.M. and Spencer, J.E., 1997, Geologic Map of the North Butte Area, Central Arizona: Tucson, Arizona Geological Survey Open-File Report 97-4,1 sheet, 15 pages, scale 1:24000.

If the authorship of the original physical map image is also responsible for production of a vector-format digital map image representing the same geologic data set, the title includes "Digital geologic map of..." followed by the same title as the physical map image. If deemed appropriate, other persons responsible for data conversion accuracy and digital cartography may be added to the author list, otherwise they should be acknowledged appropriately on the map surround. As in the case of a scanned map (case 3) the scale is labeled 'map layout scale', which is the scale at which the original cartographic design was done, because the digital image may be displayed at widely-varying scales.

Richard, S.M., Spencer, J.E., and Orr, T.R., 1999, Digital geologic map of the North Butte Area, Central Arizona: Tucson, Arizona Geological Survey Digital Information Series DI-999, 2 Adobe Acrobat (pdf) files, map layout scale 1:24000.

Doe, J., 1998, Digital geologic map of the Walkers quadrangle, Virginia: Richmond, Virginia Division of Mineral Resources Digital Publication DP-5, 1 encapsulated postscript (eps) file, map layout scale 1:24000.

If the vector-format digital map image is the original publication of the geologic data set, the map image is cited in the same fashion, with authorship determined by mutual consent of those involved. In this example, Rader and Gathright did the field work to produce the map, and produced the digital map image.

Rader, E.K., and Gathright, T.M., II, 1998, Digital geologic map of the Front Royal 30 by 60 minute quadrangle, Virginia: Richmond, Virginia Division of Mineral Resources Digital Publication DP-9, 1 encapsulated postscript (eps) file, map layout scale 1:100,000.

5. **Map image modified from digital, vector-format representation of a published map image.** The map image is modified from the original source by combining map units, deleting or adding some point data symbols, reinterpreting nature of boundaries between units,

adjusting location of faults and contacts. With enough changes, this sort of modification eventually results in a compiled data set, in which case the citation would be that for a compiled map image (case 2 above), or a data anthology (case 9). This is a judgement call on the part of the producer of the derivative map.

Reynolds, S.J., 1999, Laramide igneous rocks in the North Butte Area, Central Arizona: Phoenix, Wide World of Maps, 1 sheet, scale 1:50000. Based on Richard, S.M., Spencer, J.E., and Orr, T.R., 1997, Digital Geologic Map of the North Butte Area, Central Arizona: Tucson, Arizona Geological Survey DI-999, 2 Adobe Acrobat (pdf) files, map layout scale 1:24000.

6. **Digital map image represents the same geologic data set as a published digital geologic data set by the same authorship.** This differs from case 1, because the map image is digital, and from case 4 because digital data representing the same geologic data set are published. If only one version of the digital data set is published, and the digital geologic map image represents the same data set as the published digital data set, a relationship to the digital data set does not need to be included in the citation. The map image should always have a separate citation from the digital data set because one or the other might be updated independently.

Ferguson, C.A., and Enders, M.S., compilers, 2000, Geologic map and cross sections of the Clifton-Morenci area; Coronado Mountain, Mitchell Peak, Copperplate Gulch, and Clifton 7.5' quadrangles, Greenlee County, Arizona: Tucson, Arizona Geological Survey Digital Information Series DI-19, 1 Adobe Acrobat (pdf) file (3 plates with text), and other files, map layout scale 1:24,000.

If the digital data set is subject to updates, then a relationship to the particular instance of the data set used to generate the map image must be included in the citation. File format information for the underlying digital data set may be omitted for brevity.

Ferguson, C.A., and Enders, M.S., compilers, 2000, Geologic map and cross sections of the Clifton-Morenci area; Coronado Mountain, Mitchell Peak, Copperplate Gulch, and Clifton 7.5' quadrangles, Greenlee County, Arizona: Tucson, Arizona Geological Survey Digital Information Series DI-19, 1 Adobe Acrobat (pdf) file (3 plates with text), and other files, map layout scale 1:24,000. Derived from Ferguson, C.A., Enders, M.S., and Orr, T.R., 2000, Geologic Spatial Data for the Clifton-Morenci area, Greenlee County, Arizona (ver. 2.2): Tucson, Arizona Geological Survey Digital Information Series DI-18.2.2.

7. **Map image produced by selection and symbolization of features from an existing digital geologic data set or database.** Authorship of map image is different from authorship of digital data. Authorship role is 'compiler'. File format information for the underlying digital data set may be omitted for brevity.

Richard, S.M., compiler, 2000, Geologic map of Tertiary rocks in the Clifton-Morenci area, Greenlee County, Arizona: Tucson, Arizona Geological Survey Open-File Report 00-000, 1 sheet, scale 1:50,000. Derived from Ferguson, C.A., Enders, M.S., and Orr, T.R., 2000, Geologic spatial data for the Clifton-Morenci area, Greenlee County, Arizona: Tucson, Arizona Geological Survey Digital Information Series DI-18, 5 ArcInfo export (e00) files, 36 ESRI shape (shp) files, and other files.

Pearthree, P.A., compiler, 2005, Quaternary geology of Yavapai County: Arizona, Tucson, Arizona Geological Survey Open-File Report 05-0053, 1 sheet, scale 1:500,000. Derived from Arizona Geological Survey, 2005, Geologic Spatial Data for Arizona (ver. 6.2): Tucson, Arizona Geological Survey Digital Information Series DI-99.6.2.

Orr, T.R., compiler, 2002, Map showing approximate potassium content of bedrock formations in the Grasshopper Junction area, Mohave County, Arizona: Tucson, Arizona Geological Survey Open-File Report 02-32, 1 sheet, scale 1:50000. Derived from Gray, F. P, 2002, Geologic spatial data for the Needles 1 by 2-degree quadrangle (ver. 2): Tucson, Arizona Geological Survey Digital Information Series DI-41.2, 5 MapInfo (mif/mid) files, 1 Adobe Acrobat (pdf) file.

8. **Map image is generated by a geoscience database query and automated cartographic procedures**. The map image reflects the current state of the database. Cartographic design is founded in the design of the map query and automated cartographic procedures. The map extent and choice of features to symbolize may be unique to this particular map. Intellectual authorship for the geologic data set is based on sources of individual geologic features selected to symbolize by the query. Authorship of view is institutional. The map image must include citations for sources of all geologic data represented on map, and an index map showing the extent of data sources. Reference to database must include time stamp or version identification. File format information for the underlying digital data set may be omitted for brevity. If the source database is updated continuously, the institution maintaining the database must time stamp individual features and archive superseded features to document evolution of the database.

Arizona Geological Survey, 2009, Digital geologic map of the proposed White Tank National Monument, Maricopa County, Arizona [View]: Tucson, Arizona Geological Survey Map on Demand MOD-77, 1 Adobe Acrobat file, map layout scale 1:50,000. Derived from Arizona Geological Survey, 2009, Geologic Spatial Database for Arizona (ver. 10.6): Tucson, Arizona Geological Survey Digital Information Series DI-99.10.6.

9. **Map image represents modification of part of a published map image without the collaboration of the**

original authors or review of the entire data set. The modifications involve changes to the underlying geologic data set. The modified map represents the same geographic extent, and the cartographic design remains the same. This situation will arise for geological surveys that wish to include reliable, up-to-date information on maps they provide to users. New data may supersede parts of a geologic data set represented on a published map image, and it is desirable to update the map image with the new data. The authorship of the new data is different from the authorship of the original data set, and the authorship of the original data set is not involved in the update. The map image becomes a geologic data anthology as opposed to a compilation, because there is no single authorship for the entire data set represented by the image. The word "[anthology]" should be appended to the title. If the total number of authors involved is small (6?) include all authors in the citation, and specify the author role to be 'contributors'. Order of authorship should reflect the relative contribution to the map. If this is indeterminate, authors should be listed in alphabetical order. If the number of authors becomes large, or questions of order of authorship cannot be resolved, the map should be cited with institutional authorship. The map must include an index map showing the extent of updates and documenting the authorship and date of all updates. Update history must be documented by establishing version identification or a time-stamp that becomes part of the citation. The publishing agency must maintain archival materials documenting all updates to the map. The following examples show progressive development of an anthology.

Richard, S.M., compiler, 2000, Digital geologic map of the Globe 30' X 60' quadrangle: Tucson, Arizona Geological Survey Digital Information Series DI-33, 2 Adobe Acrobat (pdf) Files, map layout scale 1:100,000.

Richard, S.M., and Spencer, J.E., compilers, 2001, Digital geologic map of the Globe 30' X 60' quadrangle (ver. 2): Tucson, Arizona Geological Survey Digital Information Series DI-33.2, 2 Adobe Acrobat (pdf) Files, map layout scale 1:100,000.

Richard, S.M., Wrucke, C.A., and Spencer, J.E., contributors, 2003, Digital geologic map of the Globe 30' X 60' quadrangle [Anthology] (ver. 3): Tucson, Arizona Geological Survey Digital Information Series DI-33.3, 2 Adobe Acrobat (pdf) Files, map layout scale 1:100,000.

Random, P.P., Random, X.Y., Richard, S.M., Spencer, J.E., and Wrucke, C.A., contributors, 2008, Digital geologic map of the Globe 30' X 60' quadrangle [Anthology] (ver. 4): Tucson, Arizona Geological Survey Digital Information Series DI-33.4, 1 Brownmud Universal (uuu) File, map layout scale 1:100,000.

Arizona Geological Survey, 2010, Digital geologic map of the Globe 30' X 60' quadrangle [Anthology] (ver. 5): Tucson, Arizona Geological Survey Digital Information Series DI-33.5, 1 Solar WorldDomination (swd) File, map layout scale 1:100,000.

DIGITAL GEOLOGIC DATA EXAMPLES

The following are example citations for various sorts of digital geologic data. As in the previous section, example citations to Virginia maps are based on examples in Berquist (1999), and are included to show how they fit into the scheme proposed here. A citation for any digital geologic data set should clearly define the source of the underlying geologic data set, the publisher of the data set, and the number and format of the file(s) that contain the data set and any associated text. The physical media (floppy disks, CDROM, DVD....) that contain the files is not essential to an intellectual citation, since the files can be copied between media, or may be transferred directly across a network. For library cataloging purposes, the physical media would need to be noted as well.

10. **Digital geologic data set derived from a single published source.** In these examples, Richard and Thieme, and Smith were responsible for the conversion of the published map image to a digital geologic data set. Citation of the geologic spatial data is appropriate when something particular to that specific digital data set is being cited. If the underlying geologic data set is being cited, the citation should be to the original published map image.

    Richard, S.M., and Thieme, J.P., compilers, 2000, Geologic Spatial Data for the Phoenix North 30' x 60' Quadrangle: Tucson, Arizona Geological Survey Digital Information Series DI-4 (ver. 2), 3 ArcInfo Export (e00) files, 3 ESRI Shape (shp) files, 1 Adobe Acrobat (pdf) file. Adapted from Reynolds, S.J., and Grubensky, M.J., 1993, Geological Map of the Phoenix North, Central Arizona: Tucson, Arizona Geological Survey Open-File Report 93-17, 1 sheet, scale 1:100,000.

    Smith, Jane, compiler, 1998, Geologic spatial data for the Walkers quadrangle, Virginia: Richmond, Virginia Division of Mineral Resources Digital Publication DP-6, 4 AutoDesk Autocad Interchange (dxf) files, 1 Microsoft Word (doc) file, 3 dBase database (dbf) files. Adapted from Doe, John, 1997, Geologic map of the Walker Quadrangle, Virginia [scan]: Richmond, Virginia Division of Mineral Resources Manuscript Map 97-3, 1 tagged image format (tif) file, map layout scale 1:24,000.

11. **Digital geologic data set derived from field data collected under a single authorship, or from an unpublished manuscript map compiled under a single authorship (no citable version of map image exists).** If the data set is updateable, the citation must include version identification or a time stamp to document the database state cited. The date in the citation is the release date for the data actually cited. In this

example, geologic mapping was by Ferguson and Enders, and the field data were digitized and edited by Ferguson and Orr. The data set is not versioned or time-stamped, implying that there is only one extant version of the data set.

Ferguson, C.A., Enders, M.S., and Orr, T.R., 2000, Geologic spatial data for the Clifton-Morenci area; Coronado Mountain, Mitchell Peak, Copperplate Gulch, and Clifton 7.5' quadrangles, Greenlee County, Arizona: Tucson, Arizona Geological Survey Digital Information Series DI-18, 5 ArcInfo export (e00) files, 36 ESRI shape (shp) files, and other files.

12. **A compiled geologic spatial data set that includes data from a variety of authors, and is independent of any particular map image.** Citation of authorship with a compiler role denotes that the authorship has reviewed data from source data sets for consistency and reconciled any discrepancies, and has edited the complete data set for accuracy. If the data set is versioned, version identification must be included in the citation, along with the version release date. Authorship may change between versions, but citation of authorship as compilers always denotes that the entire dataset has been reviewed and edited as necessary. Determination if a compilation is a new version of an existing compilation or a new work must be decided based on institutional guidelines or agreement by the authors. The spatial extent must be identical in order to qualify as an update of an existing compilation. If a data set is updated periodically and updates are not too numerous, revision dates should be listed (revised 2000, July 5; 2001, March 15; 2001, Sept. 27). If this becomes untenable, the citation must include a date that exactly defines the cited data set (e.g. dated 2000, July 5, 3 p.m.). A continuously updated data set must include information on the origin and update history of all updateable features. The version identifier or release date for the data set cited is indicated in parenthesis after the data set title. The year listed in the citation is for the release date of the data actually cited.

In this example citation for a versioned database, Richard and Orr compiled, reviewed, digitized and edited the data. Version 2.1 was released in 2002.

Richard, S.M., and Orr, T.M., compilers, 2002, Geologic spatial data for the Globe 30 by 60 minute quadrangle, Arizona (ver. 2.1): Tucson, Arizona Geological Survey Digital Information Series DI-22.2.1, 6 ArcInfo export (e00) files, 1 Microsoft Access Database (mdb) file.

In this example citation for a continuously updated database, Berquist, Uschner, and Ambroziak compiled, reviewed, digitized and edited the data. The cited data were released July 5, 2000. The time stamp is included in parenthesis after the series title and number.

Berquist, C.R., Jr., Uschner, N.E., and Ambroziak, R.A., compilers, 2000, Geologic spatial data for the State of Virginia (dated 2000, July 5): Richmond, Virginia Division of Mineral Resources Digital Publication DP-14-B, 15 ArcInfo export (e00) files, 1 Microsoft Access Database (mdb) file, 1 Adobe Acrobat (pdf) file.

13. **Geologic spatial data derived by conversion of a published data set to a different logical schema or implementation environment.** The data conversion is designed to preserve the information content of the original dataset, but some information may be lost or corrupted. Conversion is beyond the control of the original database compiler(s). Intellectual authorship of geologic data set remains the same, and should retain primacy in the citation. Data conversion information is indicated by an 'adapted by..' (in italics) clause after the publisher and series identifier for the original data. The data conversion authorship, the date of conversion, publisher of the data in the new format, and file format for the new version must be included.

Richard, S.M., and Orr, T.M., compilers, 2002, Geologic spatial data for the Globe 30 by 60 minute quadrangle, Arizona (ver. 2.1): Tucson, Arizona Geological Survey Digital Information Series DI-22.2.1, adapted by Stanley, M.S., 2003, Tucson, Arizona, RSI Inc., 6 Map/Info (mif) files, 1 Lotus Approach Database (lad) file.

14. **A variety of data sets are combined in a single data structure by authors operating independently.** This may be the case for a single or compiled data set updated by an authorship different from the original authorship, or for a database consisting of data sets from multiple sources that have not been compiled. The result is a data anthology or database. There is no single authorship for the entire data set. Authorship citation follows the conventions suggested in case 9 above. The word "[anthology]" should be appended to the title. If the total number of authors involved is small (6?) include all authors in the citation, and specify the author role to be 'contributors'. Order of authorship should reflect the relative contribution to the map. If this is indeterminate, authors should be listed in alphabetical order. If the number of authors becomes large, or questions of order of authorship cannot be resolved, the database should be cited with institutional authorship. Such a database must maintain tracking records to document the origin of the geologic data contained therein. The tracking record must include citation information for all original sources of data. If the database is updated in a succession of versions, archival copies of superceded versions must be maintained. If the database is updated

continuously, individual features must be time stamped to document the period during which they are considered current. Obsolete features must be archived, and may be removed from the current copy of the database after they are archived. Use of the term "database" in the title of a work implies that the work represents a data anthology; if the term database is not included in the title, then "[Anthology]" should appear somewhere in the title.

Richard, S.M., Spencer, J.E., Wrucke, C.M., and Orr, T.M., contributors, 2004, Geologic spatial data for the Globe 30 by 60 minute quadrangle, Arizona [anthology] (ver. 4.1): Tucson, Arizona Geological Survey Digital Information Series DI-22.4.1, 6 ArcInfo export (e00) files, 1 Microsoft Access Database (mdb) file.

Arizona Geological Survey, 2009, Geologic spatial database for Arizona (ver. 10.6): Tucson, Arizona Geological Survey Digital Information Series DI-99.10.6, 1 ESRI Geodatabase, 1 Microsoft Access database (mdb) file, 1 Adobe Acrobat (pdf) file.

Arizona Dept. Water Resources, 2005, Geologic spatial data for the Tucson Basin [anthology] (ver. 0.5): Phoenix, Arizona Dept. Water Resources Open-File Database 22, 1 Manifold database (mfd) file, 1 Microsoft Access database (mdb) file, 1 Adobe Acrobat (pdf) file.

NOTE:

It is important to inform users of the conventions used for authorship and citation (Berquist, 1999). To insure consistent citation of the data, include statements similar to the following text on any published map image, printed on the physical media used to deliver digital data, and in a 'Readme' file included with any data or map image that is transferred electronically:

Digital Publication 7 - Appalachia Quadrangle

Digital Publication DP-7-A is a digital geologic map image. The bibliographic citation for geologic content of this image is as follows:

Nolde, J.E., Henderson, Jr., and Miller, R.L., 1988, Geology of the Virginia portion of the Appalachia and Benham quadrangles: Richmond, Virginia Division of Mineral Resources Publication 72, 1 sheet, scale 1:125,000.

Bibliographic citation specifically to this digital file:

Virginia Division of Mineral Resources, 1998, Digital representation of geologic map of the Virginia portion of the Appalachia quadrangle: Richmond, Virginia Division of Mineral Resources Digital Publication DP-7-A, 1 encapsulated postscript (eps) file, map layout scale 1:125,000. *Adapted from* Nolde, J.E., Henderson, Jr., and Miller, R.L., 1988, Geology of the Virginia portion of the Appalachia and Benham quadrangles: Richmond, Virginia Division of Mineral Resources Publication 72, 1 sheet, scale 1:125,000.

Digital Publication DP-7-B is a digital data set. Geologic information, concepts, and other products gained from the use of these files should be credited as follows:

Uschner, N.E., Jones, K.B., Sheres, D.E., and Giorgis, S.D., 1998, Geologic spatial data for the Virginia portion of the Appalachia quadrangle: Richmond, Virginia Division of Mineral Resources Digital Publication DP-7-B, 7 ESRI shape (shp) files. *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, 1 sheet, scale 1:125,000.

TERMINOLOGY:

Adapted from—indicates derivation of digital data from a published map image.

Adapted by—indicates derivation of digital data by conversion from a different implementation or logical data structure.

Anthology—indicates aggregation of information without complete review and editing under a single authorship.

Authorship—the collection of persons responsible for the content of a document. 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.

Based on—indicates production of a map image by minor revision of another map image.

Cartographic design—the process of choosing the graphical elements to represent geographic features and related information on a map image, and arranging the elements for maximum legibility and clarity.

Citation—The formal identification of a document. A citation must specify the authorship, title, date of publication, particular version of a document if it is subject to update, publisher, publisher's identification for work, and medium that contains the work. If a document is derived from another document, the citation should specify the relationship to the other document and cite the original document.

Compilation—integration of data from several sources, including review for consistency and resolution of inconsistencies.

Contributor—a role specifier that indicates independent authorship of different parts of a geologic data set.

Data conversion—process of converting data representation from lines and symbols on a physical map image to digital file(s).

Data editing—reviewing compiled or converted data for accuracy, and correcting errors in topology, location, or classification to be consistent with the original source.

Derived from—indicates that a map image was produced directly from a digital geologic data set.

Digital map image—a map image in a digital-encoded form that requires the use of machinery to render in a form that is useful to humans.

Digital publication—a citable electronic document that has an immutable identity.

Display—rendering of a map image to a visible form, either on a screen or on paper.

Document—the original, official, or legal form of something, which can be used to furnish decisive evidence or information. This is generalized from The American Heritage Dictionary (Second College Edition, 1982) by removing the restriction that the representation be contained on paper.

Geologic data set—collection of map unit definitions, interpretations of the nature of the boundaries between the map units, locations of faults and boundaries between the map units defined, and descriptions (quantitative and qualitative) of the internal structure of the map units.

Institutional authorship—Applied to geologic data sets that evolve over time as updates are made, and to map images that represent such data sets. Updates are not reviewed and approved by a single authorship. Authority for maintenance of the data set resides with a particular institution, and is based on the standards for accuracy and reliability of the institution. Document so cited has rank of an anthology.

Map image—a particular visualization of the interpretation of geologic data for an area, defined by the bounding polygon for the map area, the map projection, the elevation model for the surface represented, the geologic data used, the choice of symbols for geologic features, and the cultural and physiographic base map.

Physical Map image—map image on physical media (typically paper or film) in a form directly useful to humans.

Published database—a particular collection of data arranged in a fixed data structure. The data structure must be described in text accompanying the database or in a separate document. If the database is subject to updates, a mechanism must be defined whereby a citation to the database identifies the exact cited database state.

Publication—A document that is identified by a citation, and made available through some public venue.

REFERENCES

Berquist Jr., C.R., 1999, Digital map production and publication by geological survey organizations; A proposal for authorship and citation guidelines, in Soller, D.R., ed., Digital Mapping Techniques '99—Workshop Proceedings: U.S. Geological Survey Open-File Report 99-386, p. 39-42, <http://pubs.usgs.gov/openfile/of99-386/berquist.html>.

U.S. Geological Survey, 1995, Draft cartographic and digital standard for geologic map information: U.S. Geological Survey Open-File Report 95-525, pagination varies.

NSGIC — A Resource for State Geologists

By Susan Carson Lambert

President Elect, 2000
National States Geographic Information Council
67 W. Main St., Suite 600
Lexington, KY 40507
Telephone: (859) 514-9208
Fax: (859) 514-9188
e-mail: Susan.lambert@mail.state.ky.us

WHAT IS NSGIC?

The National States Geographic Information Council (NSGIC) is an organization of States committed to efficient and effective government through the prudent adoption of information technology. Members of NSGIC include delegations of senior state geographic information system managers from across the United States. Other members include representatives from federal agencies, local government, the private sector, academia and other professional organizations. A rich and diverse group, the NSGIC membership includes nationally and internationally recognized experts in geographic information systems (GIS), and data and information technology policy.

NSGIC is particularly concerned with geographic data and systems. This technology helps create intelligent maps and data bases that enable public and private decision makers to make better informed and more timely decisions in a wide array of governmental areas. This technology can affect such diverse areas as economic development, delivery of health and human services, environmental protection, facilities management, taxation, education, emergency government, and transportation. GIS systems and data are rapidly becoming principal tools in the business of government and the private sector because they are visual, integrative, intelligent and analytical. In addition, GIS provides the means to eliminate needlessly redundant work within and between units of governments; to provide operational efficiencies; and to capture economies of scale in information handling and distribution.

The implications of GIS technology and data are profound. Location is the single common thread to all data. In the not-too-distant future, nearly every governmental unit will adopt a geographic or locational organization scheme to tie governmental information together for improved data administration. Simply, geographically based information technology and data can enhance the usefulness of, and the returns from, the investment in public information. Nevertheless, the potential benefits of the technology and data can only be realized through intergovernmental and private sector cooperation, and partnerships.

PURPOSE

The NSGIC Bylaws provide that the purpose of the Council is to encourage effective and efficient government through the coordinated development of geographic information and related technologies to ensure that information may be integrated at all levels of government.

ACTIVITIES

The Council's efforts and focus include:

Policy

NSGIC provides a unified State voice on geographic information and technology issues, advocates State interests, and supports the membership in their individual initiatives. The Council actively promotes prudent geographic information integration and systems development. NSGIC reviews legislative and agency actions, promotes positive legislative actions, and provides advice to public and private decision makers.

In accepting these challenges, NSGIC has had profound influence on the development of policy on a national level. NSGIC members have served on a variety of task forces and working groups relative to the National Spatial Data Infrastructure. NSGIC's influence has been felt within many states as well by providing speakers and education that have helped states to form sensible, productive policies toward the coordinated development of technology and data.

Liaison and Networking

NSGIC promotes interaction and cooperation among Council members, federal, local and regional governments, professional associations, and public and private sector groups. NSGIC publishes a quarterly newsletter to keep members abreast of Council activities and breaking developments. The newsletter provides a forum for state activities, technical issues, and general interest. The Council also maintains a bulletin board which is accessible via the Internet and a listserve. The NSGIC web site is <http://www.nsgic.org>.

Research

The Council studies and provides a forum for examining geographic information issues. NSGIC provides resources and personnel to facilitate the research and testing of geographic information and technology concepts, applications, policies, and coordination mechanisms. The Council has conducted several surveys, issue papers and proposals in a number of technical and policy areas. Council members get complementary copies of all work.

Education and Public Relations

NSGIC develops and helps others develop, a variety of educational programs and materials through a variety of media to enhance and promote discussion of ideas regarding geographic information management and integration. Of particular importance is the NSGIC annual conference. This meeting takes a unique approach—it is an educational program, but it also is a working session where the Council develops policy, works on technical issues, and provides in-depth analysis of issues and opportunities.

Vendor Presentations and Contact Information

This Digital Mapping Techniques workshop was attended by technical experts from selected software and hardware companies. These individuals provided technical trouble-shooting and general information needed by the geological survey workshop attendees, and the workshop organizers offer sincere thanks for their significant contributions to the meeting. The DMT workshop series is designed as a collegial event, where information is freely shared, in recognition of a common set of goals. Our colleagues in the vendor community certainly contributed to the workshop's success. Their contact information is given below.

Mike Price (Environmental Systems Research Institute, Inc., [ESRI]) provided technical guidance and support for ESRI products, and an oral presentation entitled "New Developments in ESRI GIS Technology: ArcInfo, ArcView, ArcPad, and ArcIMS." Additional information concerning the latest revisions to ArcInfo (v.8) can be found at <http://www.esri.com/library/whitepapers/pdfs/ai8_newmill.pdf> (approx. 1.1MB).

Mike Price, Mining Industry Manager
Environmental Systems Research Institute, Inc.
380 New York St.,
Redlands, CA 92373-8100
Telephone: (909) 793-2853, extension 11677
e-mail: mprice@esri.com
Corporate Web site: <http://www.esri.com>

John Kramer (Condor Earth Technologies, Inc.) provided an overview of field data-capture systems, in a presentation entitled "Digital Mapping Systems for Field Data Collection." The presentation was supported by a paper in these Proceedings.

John H. Kramer
Condor Earth Technologies, Inc.
21663 Brian Lane
Sonora, CA 95251-3905
Telephone: (209) 532-0361
Fax: (209) 532-0773
e-mail: jkramer@condorearth.com
Corporate Web site: <http://www.condorearth.com>

John Ditomasso (Hewlett Packard Co.) provided an overview of HP plotters, plotter technology, and the various available media, in an oral presentation entitled "Discussion of Hewlett Packard DesignJet plotters and media."

John DiTomasso, Account Manager, Digital Imaging Products
Hewlett Packard Co.
2101 Gaither Road
Rockville, MD 20850
Telephone: (301) 258-2231
e-mail: john_ditomasso@hp.com
Corporate Web site: <http://www.hp.com/>

Techni Graphics Systems and Smallworld provided technical support and coauthorship for a presentation on building a prototype map database (Wahl and others, this volume).

Roger A. Fredericks, Business Development Manager
Techni Graphic Systems, Inc.
2301 Research Blvd., Suite 101
Fort Collins, CO 80526
Telephone: (970) 224-4996
Fax: (970) 224-3001
e-mail: rogerf@tgstech.com
Corporate Web site: <http://www.tgstech.com>

Robert Laudati
Smallworld Systems, Inc.
5600 Greenwood Plaza Blvd., Suite 300
Englewood, CO 80111
Telephone: (303) 779-6980
e-mail: robert.laudati@smallworld-us.com
Corporate Web site: <http://www.swldy.com>

The Process of Presenting GIS Information — Making GIS User-Friendly

By Kimberly H. Sowder, Richard T. Hill, and Paul N. Irwin

Indiana Geological Survey
611 N. Walnut Grove
Bloomington, Indiana 47405-2208
Telephone: (812) 855-3951
Fax: (812) 855-2862
e-mail: sowderk@indiana.edu, hill2@indiana.edu, irwinp@indiana.edu

There are always unexpected problems in a Geographic Information System (GIS) project that arise and must be dealt with — sometimes in innovative ways. But once the data have been neatly tucked away in themes and fields, rows and columns, the final problem remains of how to present them to the general user. Consideration should be paid to the end-user who may not have access to GIS software and an adequate or existing Internet connection. The method described here has provided a new format for the Indiana Geological Survey (IGS) to present, distribute, and publish its GIS data. GIS data are versatile, but expensive to create. Making this information easily accessible and widely available to a large client base fulfills an essential part of the IGS mission and is a good business practice.

In 1999, a project was undertaken by the IGS in cooperation with the Illinois State Geological Survey and Kentucky Geological Survey to convert the data from the 1994 Gas Research Institute (GRI)/Illinois Basin Consortium (IBC) publication "Gas Potential of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin" into a GIS. This project, which was funded in part by GRI, is the focus of this presentation. The original GRI/IBC publication consisted of an 83-page illustrated report, bibliography, reference section, and seven large-format plates of the study area. Six of these plates were maps at a scale of 1:1,000,000, and the seventh plate was a series of stratigraphic cross sections spanning the Illinois Basin.

Early in the process it was determined that the report would be scanned and converted into PDF format, and the map information (originally in AutoCAD format) would be converted via ArcCAD and ArcView into a GIS format. However, the project at this stage did not consider the abilities of all potential users of the information.

The problems of how to present the data lingered. The decision was made to include Acrobat Reader (a no-cost application) as a means of viewing the final text files and cross sections in a PDF format. ArcView users were provided with the ArcView project file to access the data. Users not familiar with ArcView were supported by providing ArcExplorer software (also a no-cost application) as a means of viewing the Environmental Systems Research, Inc. (ESRI) shape files. Views and layouts from the ArcView APR file were recreated in ArcExplorer AEP format. The creation of the AEP files presented a new set of challenges, as the database structure for several coverages did not lend itself to easily establishing ranges and color ramps in ArcExplorer. To compensate for this, fields were added to the databases to create ranges for displaying the groupings of data. This allowed for easy display and color ramping of these pre-established ranges. The appearance of the ArcExplorer layouts and the ArcView layouts was kept as similar as possible.

The cross sections from the large plate were scanned in sections, reassembled, saved in TIF format, and exported into PDF format. The TIF files were also provided for those users who have large-format plotters and would like a high-resolution plottable file. The PDF files were then hot-linked in the ArcView project file so that the appropriate cross section opens when the displayed line on the corresponding map is selected with the "lightning bolt" icon. This required additional programming in ArcView. However, the PDF is much easier to manipulate and view than the more sizeable TIF file, which was an important outcome because the cross sections were originally as much as forty inches in width.

CD-ROMs were the chosen media for distributing the information because this simplifies pricing and sales, allows for easy and fast access to the information, and avoids using web resources on a long-term basis.

Additional CD-ROMs can be reproduced easily and economically; the information on this media is also secure and static.

A user-friendly interface between the data and the end-user was deemed desirable. Originally, a web browser interface was evaluated. The low cost of creating HTML files and the ability to make the interface attractive and interactive was appealing. The web browser interface, however, is not readily made compatible across different browsers and different browser versions. After researching several options, Demo Shield software was chosen. Any Windows 95, 98, NT, or 2000 platform user can access the information through Demo Shield's interface. Navigation buttons and menu screens were created to ease the installation of ArcExplorer and Acrobat applications. Links to files also allowed for the viewing of ArcExplorer plates and metadata in HTML format. Additional buttons and screens also allowed for graceful integration of legal information such as disclaimers, copyrights, and agreements of use. The ArcView project file cannot be directly viewed using a navigation button, but a Windows explorer screen can be automatically launched, allowing the end-user to double-click on the file and launch ArcView.

Once all the data files were reviewed and received final approval from the three cooperating state surveys, the ArcView and ArcExplorer project files were opened in Microsoft WordPad and "relative-pathed" to enable opening and access on any Windows-based PC from the CD-ROM drive. All files were then copied to CD-ROM and 1,000 copies reproduced for sale. The CD-ROM will start upon insertion if the user has the Autorun option selected on his PC. The CD-ROM has a finished appearance and professional look, and provides a means of easy access to all data.

The project data on CD-ROM can be purchased from the following:

Publication Sales
Indiana Geological Survey
611 North Walnut Grove
Bloomington, Indiana 47405
Tel: (812) 855-7636
Fax: (812) 855-2862
e-mail: igsinfo@indiana.edu

Kentucky Geological Survey
228 Mining and Mineral Resource Building
University of Kentucky
Lexington, Kentucky 40506-0107
Tel: (859) 257-5500
Fax: (859) 257-1147

Information Office
Illinois State Geological Survey
615 E. Peabody
Champaign, IL 61820
Tel: (217) 244-2414
Fax: (217) 244-0802
e-mail: isgs@geoserv.isgs.uiuc.edu

REFERENCE

Hasenmueller, N.R., and Comer, J.B., eds., 1994, Gas potential of the New Albany Shale (Devonian and Mississippian) in the Illinois Basin: Illinois Basin Consortium, Gas Research Institute 92-0391/Illinois Basin Studies 2, 83 p.

Integrated Geospatial Data: Irvine 30 x 60 Minute Quadrangle, East-Central Kentucky

By Douglas C. Curl

Kentucky Geological Survey
228 Mining and Mineral Resources Building
University of Kentucky
Lexington, KY 40506-0107
Telephone: (859) 257-5500
Fax: (859) 257-1147
e-mail: dcurl@kgs.mm.uky.edu

ABSTRACT

The Kentucky Geological Survey has a 160 year history of mapping the geology and resources of Kentucky. The advent of GIS technology has given mappers and map users greater access to mapped geologic data and more analytical power than ever before; however these advantages can only be realized if maps are in the proper digital format. Therefore, KGS is converting traditional data into geospatial digital products that can be used in modern geographic information systems. Geospatial data available for the Irvine 30 x 60 minute quadrangle map exemplifies the type of geospatial data that KGS is compiling:

- Digital geologic map data (Figure 1)
- Domestic water-well and spring data (Figure 1 and 2)
- Oil- and gas- well locations (Figure 3)
- Structural contour data for several formations, including various coal formations, the Mississippian Newman Formation, the Mississippian "Big Lime" formation (an important oil-producing formation), and the Precambrian basement (Figure 3)
- Coal beds and coal outcrop locations (Figure 4)
- Fossil locations (Figure 4)
- Digital elevation models of USGS 7.5-minute topographic quadrangle maps (Figure 2).

The digital geologic map of the Irvine 30 x 60-minute quadrangle is a compilation of data digitized from the original 7.5-minute geologic quadrangle maps. Compiling 32 individual 7.5-minute maps into one 30 x 60 minute map required resolving significant geologic correlation and continuity problems between quadrangles. Stratigraphic and lithologic inconsistencies on most individual 7.5-minute quadrangle maps meant that compilation of maps required geologic evaluation and additional or new data to create an accurate 30 x 60 minute geologic map at a scale of 1:100,000.

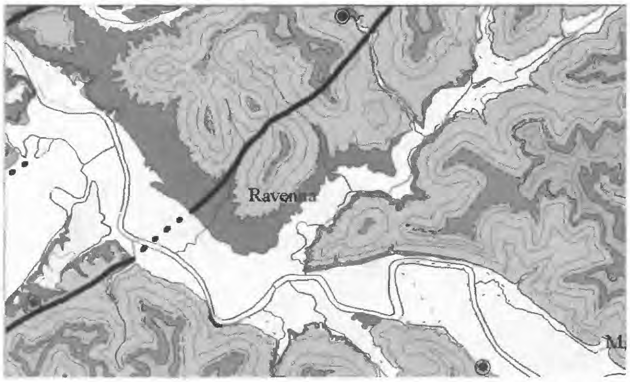

Figure 1. Portion of the Irvine 30 x 60 minute quadrangle map showing the digital geologic data and domestic water well data (double circles). The primary digital geologic data includes lithologic contacts, shown as both inferred (dashed) and known (solid); lithologic polygons; and fault traces (heavy dark solid and dashed lines).

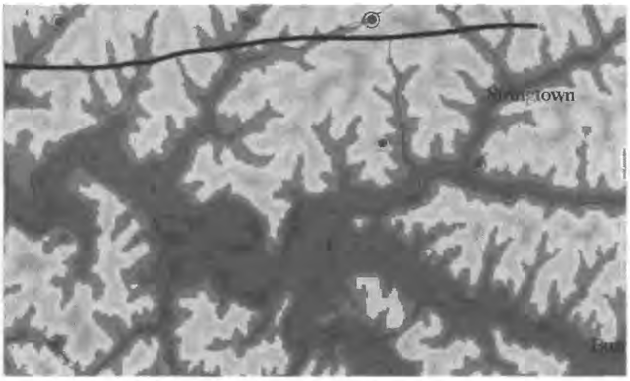

Figure 2. Portion of the Irvine 30 x 60 minute quadrangle map with the USGS Digital elevation models as the base map with an overlay of domestic water well and spring data (double circles).

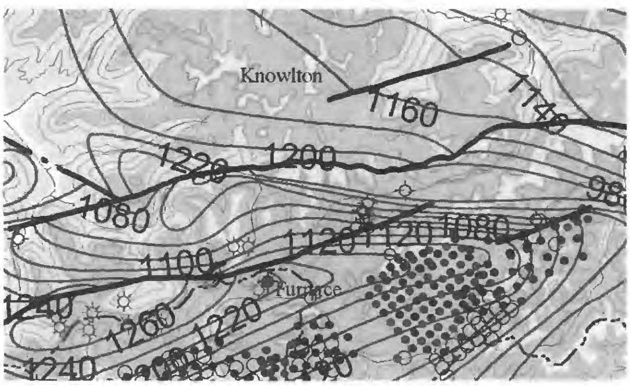

Figure 3. Portion of the Irvine 30 x 60 minute quadrangle map showing oil and gas well locations (dots), and structural contours on the Mississippian Newman Formation (thick grey lines with number labels). The base map here is the digital geologic map data, and the heavy dark lines are fault traces.

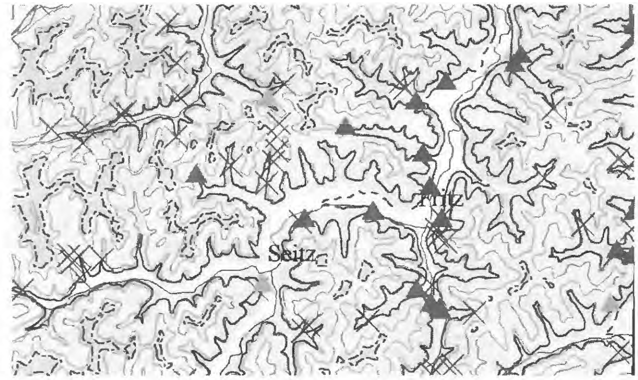

Figure 4. Portion of the Irvine 30 x 60 minute quadrangle map showing coal beds (dark solid and dashed lines), coal outcrop locations (shaded triangles), and fossil locations (grey X's). The base map here is the digital geologic map data.

Digital Geologic Map of the Jackson Purchase Region, Western Kentucky

By Steven L. Martin

Kentucky Geological Survey
228 Mining and Mineral Resources Building
University of Kentucky
Lexington, KY 40506-0107
Telephone: (859) 257-5500
Fax: (859) 257-1147
e-mail: smartin@kgs.mm.uky.edu

ABSTRACT

The Jackson Purchase Region of western Kentucky is located in the northeastern part of the Mississippian Embayment. Rocks and sediments exposed in the region range in age from Devonian to Holocene. The digital geologic map of the Jackson Purchase Region is compiled from portions of forty-seven 1:24,000-scale geologic quadrangle maps from the Sikeston, Cape Girardeau, Paducah, and Murray 30 x 60-minute sheets. This map shows formations, faults, and structure contours that were digitized from the original geologic maps. Aeromagnetic geophysical data and a map showing the top of Paleozoic bedrock are also included to show that data from other sources can be integrated with the digital geologic data.

A goal of this project is to construct a seamless geologic map for the Jackson Purchase Region; there are stratigraphic discrepancies between formations along some quadrangle boundaries, however. These discrepancies usually occur because of the original mapper's differing opinions and interpretations, and because different topographic base maps were used. Stratigraphic problems encountered during edgematching of 7.5-minute geologic quadrangles include disparities between: (1) the Jackson Formation (Tj), the Claiborne Formation (Tc), and the Wilcox Formation (Tw); (2) the Clayton and McNairy Formation undifferentiated (TKcm) and the McNairy Formation (Km); and (3) Quaternary alluvial deposits (Qal) along alluvial stream valleys. The discrepancies between the Jackson, Claiborne, and Wilcox Formations were resolved by using compilation maps and data from the original mappers. The contact between the Clayton Formation and the McNairy Formation is difficult to map because of the lack of exposure and lithologic similarities. This discordance was solved by changing formation names along quadrangle boundaries where the disparities occurred according to original geologic map data and compilation maps of the area. Discrepancies also occurred between interpreted Qal boundaries in alluvial stream valleys because different base maps were being used, and because some alluvial valleys were mapped at different topographic elevations. Most of the discrepancies occur in smaller alluvial stream valleys that border map edges. Structural arc (i.e., structure contour lines) discrepancies also occurred along map boundaries, because each mapper's interpretation of where to draw contour lines on erosional surfaces was different.

This digital geologic map of the Jackson Purchase Region was created using ArcInfo, and includes formations and structural arc coverages. The formation coverage consists of approximately 65,000 arcs and 25,000 polygons. Formation arcs represent stratigraphic contacts, faults, and map boundaries (state and county lines), whereas formation polygons represent geologic map units. The structural arc coverage represents contour lines drawn on the erosional surfaces that cut rocks of various ages. Data captured and attributed as coverages from the original 1:24,000-scale geologic quadrangle maps, but not included on this map, include structure point, economic, drill-hole, fossil, dike, and miscellaneous coverages. Miscellaneous coverages include data on slumps, sinkholes, and other geomorphic features. Included on this map are data derived from other sources that relate to the Jackson Purchase Region, and can be integrated with the digital geologic data. Aeromagnetic flight-line data provided by the Tennessee Valley Authority consist of point data that were gridded and then contoured using ArcInfo (figure 1). The paleogeologic map and the subsurface topographic map show elevation contours of Paleozoic bedrock, and was digitized using ArcInfo (figure 2).

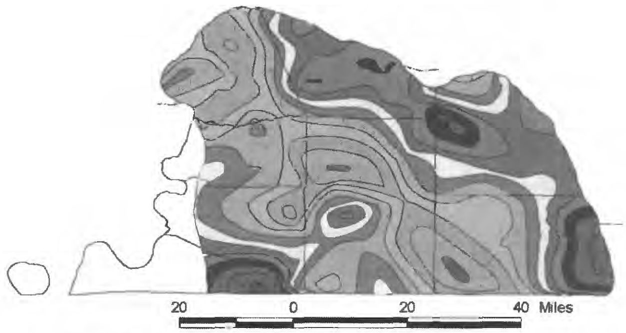

Figure 1. Magnetic anomaly map of the Jackson Purchase Region in western Kentucky. This map consists of point data provided by the Tennessee Valley Authority that has been gridded then contoured at 50 gamma intervals (Applied Geophysics, Inc., 1999).

Figure 2. Subsurface topographic map and paleogeologic map of the Paleozoic bedrock surface in the Jackson Purchase Region (Schwalb, 1969).

The discrepancies between interpreted boundaries for Quaternary alluvium (Qal) along stream valleys at map edges will be examined, and contacts altered with respect to topography on future versions of this map in order to provide continuity of mapped units between quadrangles. A stratigraphic column, lithologic descriptions, cross sections, and economic resource summary will also be included on future versions. Compiling the digital geologic quadrangle maps has provided insight to stratigraphic differences between quadrangles. This map could also be used to locate economic resources, and provide information about seismic risk, geologic hazards, and engineering construction projects in the Jackson Purchase Region.

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Bedrock Geologic Map of the Table Rock Lake, Missouri 30' x 60' Quadrangle: A Digital Compilation

By Mark A. Middendorf

Missouri Department of Natural Resources
Division of Geology and Land Survey
Geological Survey Program
P. O. Box 250
Rolla, Missouri 65402
Telephone: (573) 368-2147
Fax: (573) 368-2111
e-mail: nrmiddm@mail.dnr.state.mo.us

Geologic mapping, through U. S. Geological Survey STATEMAP and Missouri Department of Natural Resources' general revenue funding, began on the Table Rock Lake, Missouri 30' x 60' quadrangle in 1993 on two 7.5' quadrangles. In the four succeeding years, mappers and map areas increased to a total of eighteen 7.5' quadrangles of the total 32 for the study area. The remaining 7.5' quadrangles had previously been published or had a sufficient reliability (enough control data to present geologic map interpretation at a specific scale; Robertson and Middendorf, 1999) to open file the Table Rock Lake quadrangle compilation at 1:100,000-scale.

It was not until the last round of geologic mapping that ArcView was used to digitally compose the geologic data. Prior to 1997, geologic data was hand drawn by the geologist on screened mylar, and an open file layout of the map area was cut and pasted together to be run through a blue-line printer. ArcView allows a project file for each quadrangle map area to be created, with all the elements organized within the project folder. Bedrock exposures can be more faithfully depicted as to their location and extent, and attributes directly linked with these shapefiles. Support data includes bedrock outcrops, surficial material sites, structural features, water well, spring and stream data, walking and road traverses, lineament and aerial photographic studies, and any other geologically related information that makes the bedrock and surficial material interpretations more reliable.

Shapefiles for all 32 quadrangles were individually composed, either directly through ArcView or converted from .dxf files from digitized mylar copies. Discrepancies in linework between adjacent quadrangles mapped by different authors at different times makes for some compunctious editing bouts, as well as mapping composed on differing topographic bases, non-uniform map units, and quality control relating to digitizing techniques. It had been noticed that "puck" digitizing is relatively quick, but has low quality results - for example, poor line depiction at larger-scales. Recently our older maps have been scanned, which in turn can be geo-referenced, placed in a view and "heads-up" digitized with much better results. The individual quadrangles were compiled into the Table Rock Lake quadrangle, boundaries edgematched, and a layout composed of the bedrock geologic map, sources of mapping, correlation of map units and descriptions of map units and structural features.

Compiling geologic mapping at 1:100,000-scale on 30' x 60' quadrangle map areas is a great means of regionally presenting this data. Larger-scale, highly control-supported geologic mapping is offered as 1:24,000-scale digital files by the Missouri Division of Geology and Land Survey.

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Using GIS for Visualizing Earthquake Epicenters, Hypocenters, Faults and Lineaments in Montana

By Patrick J. Kennelly and Michael C. Stickney

Montana Bureau of Mines and Geology
Montana Tech of the University of Montana
Butte, MT 59701-8997
Telephone: (406) 496-2986
Fax: (406) 496-4451
e-mail: pkennelly@mtech.edu

INTRODUCTION

The Montana Bureau of Mines and Geology (MBMG) uses Geographic Information Systems (GIS) technology to map and visualize elements associated with earthquake seismicity. Due to the nature of earthquakes, the mapping process is inherently three-dimensional. Epicenters are the location of a subsurface seismic event projected vertically up to the topographic surface. The true three-dimensional location of the focus of slip is referred to as the hypocenter. Mapping locations of foreshocks, the main shock, and aftershocks in three dimensions can define the subsurface fault plane on which movement has taken place.

In many cases, larger faults extend up to the ground surface. Offset along the fault can be lateral, vertical, or a combination of both. These linear offsets are often represented in topographic landforms, including fault-bounded mountain ranges and associated valleys. Linear geologic features that do not show conclusive evidence of offset or fault origin are referred to as lineaments. Analytical hillshading of Digital Elevation Models (DEMs) can accentuate traces of faults and lineaments. Visibility of faults and lineaments is a function of the three dimensional orientation of both the surface normal vector of the topographic features and the illumination vector. Traditional filtering methods used to identify linear features on remote sensing imagery can also be utilized, although the result is not as visually striking or intuitive as using analytical hillshading. The surface can also be filtered and then hillshaded to visualize lineaments.

This paper presents data for two areas, the seismically active western portion of the state, and the seismically quiescent eastern portion. MBMG Special Publication 114 summarizes much of this data for western Montana (Stickney et. al., 2000). In addition to the data found in this report, this study presents planar regression analysis for hypocenter locations of the Norris earthquake swarm in western Montana and GIS visualization tools for the Brockton-Froid lineament in eastern Montana.

SEISMICITY IN MONTANA

Earthquake epicenters and fault traces have been compiled for the state of Montana, with an emphasis on the historically active western half of the state. In western Montana and throughout the Intermountain West, only the very largest historic earthquakes can with certainty be ascribed to specific faults. This is because western Montana earthquakes typically result from slip (movement) along faults at depths of 2–10 miles (3–15 km) below the ground surface. Only during the largest earthquakes (those generally larger than magnitude 6.5) does fault slip propagate up to, and offset, the Earth's surface. This offset of the Earth's surface results in a fault scarp. Young fault scarps (those less than 15,000 years old) mark steep mountain range fronts (Madison, Centennial, Absaroka, and Tendoy ranges for example). These mountain ranges are fault blocks uplifted by repeated earthquakes over millions of years and subsequently carved by ice and water into rugged mountains. Sediment eroded from the mountains filled broad valleys overlying the adjacent, downthrown fault blocks (Madison, Centennial, Emigrant, and Red Rock valleys).

The only historic surface-rupturing earthquake in Montana is the 1959 Hebgen Lake earthquake, centered just west of the northwest corner of Yellowstone National Park. The magnitude 7.5 Hebgen Lake earthquake offset the Earth's surface for a distance of 20 miles (32 km) along two principal faults and produced up to 20 feet (6 m) of vertical offset. Earthquakes as large as the 1959 earthquake occur infrequently (perhaps once in a few thousand to tens of thousands of years) on specific faults in western Montana.

It is these large but infrequent earthquakes that are preserved in the geologic record and modify the landscape, creating fault scarps along which a mountain block is uplifted or a valley floor is lowered. Many other faults have ruptured during the Quaternary (the past 1.6 million years) but the age of the last rupture is not well constrained. The long elapsed time since the last major earthquake on these faults may suggest they are no longer active, but their potential to produce an earthquake cannot be completely ignored because many faults in the Intermountain West have very long recurrence times.

Small- and moderate-magnitude earthquakes (magnitudes less than 6.5) generally do not alter the Earth's surface in Montana. However, they occur more frequently than surface-rupturing earthquakes and may be powerful enough to cause damage. Thus, much of the seismic hazard facing western Montana comes from smaller but more frequent earthquakes on faults lying hidden beneath the Earth's surface as well as major but infrequent earthquakes along mapped faults.

DISCUSSION OF THE MAP "QUATERNARY FAULTS AND SEISMICITY IN WESTERN MONTANA"

Topographic Data

Our digital topographic representation of western Montana is based on Digital Elevation Models (DEMs) created by the USGS. Western Montana DEMs were obtained from the Montana State Library National Resources Information System (NRIS). A full description of these data is available from the NRIS web site at <http://nris.state.mt.us>. The topographic visualization was derived from 30-meter and 3-arc-second U.S. Geological Survey DEMs. The 3-arc-second DEMs include some vertical accuracy problems, primarily in the northeast part of the map area. The data from areas with contrasting data quality were smoothed in ArcInfo GRID using filtering techniques to minimize these artifacts.

The appearance of shaded relief topography was accomplished with the aid of ArcInfo TIN conversion routines and hill-shading techniques (Stickney et. al., 2000). The visualization of the topographic surface was created by artificially illuminating the DEM with an afternoon sun source (azimuth 315 degrees, altitude 55 degrees, and vertical exaggeration 1.5). The map was created by projecting the illuminated DEM data into a Lambert Conformal Conic Projection using the Montana State Plane Coordinate System with the following parameters: Central Meridian -109.5°, 1st standard parallel 45° north, 2nd standard parallel 49.0°, origin 44.25o and false easting 600,000 meters. Other data shown on the map, such as county boundaries, lakes, rivers, highways, and cities are derived from 1:100,000-scale U.S. Census Bureau Tiger files that also were obtained from NRIS.

Faults

The Special Publication No. 114 (Stickney et.al., 2000) map displays faults, earthquakes, and topography in western Montana. Funded through the Earthquake Hazards Reduction Program, the U.S. Geological Survey (USGS) compiled Quaternary faults in western Montana as part of a larger effort sponsored by the International Lithosphere Program. The USGS conducted a detailed review of published and unpublished maps and literature concerning Quaternary faults in western Montana. Fault data were entered into a data base and used to compile a map showing the locations, ages, and estimated slip rates of Quaternary faulting in western Montana. Fault traces were taken from original sources and compiled on 1:250,000-scale quadrangle base maps and digitized for use with the GIS. In addition to location and style of faulting, the data characterize the time of most recent movement and estimated slip rate for each fault. Also included are geographic and other paleoseismologic parameters and a bibliographic reference. Information from this data base is available on CD-ROM from the Montana Bureau of Mines and Geology (Haller et. al., 2000).

Characteristics of several faults significantly change along the length of the fault (Red Rock and Madison faults for example), indicating that different parts of the fault (sections) behave independently of each other. Faults with two or three sections are indicated on the map and in the database with a lowercase letter following the fault number (i.e. 644a). If the available information does not imply a multi-sectioned fault, then the fault is described as a simple fault and designated with a three digit number (i.e., 687).

Most of the faults that have produced earthquakes in recent geologic time originated many millions of years ago. These ancient faults have moved in various ways as different tectonic events shaped Montana's geologic history. The Lewis and Clark zone is an example of a fault zone formed over a billion years ago, which may still have the potential to produce damaging earthquakes. About 12 major faults make up the Lewis and Clark zone which extends from the Helena region west-northwestward through Missoula to the Montana-Idaho state line near Lookout Pass, and beyond to the vicinity of Coeur d'Alene, Idaho. The Lewis and Clark zone is a general name describing this group of faults with horizontal offsets measured in kilometers to tens of kilometers as well as strongly deformed rock strata (Wallace and others, 1990). These faults accommodated slip during the formation of the overthrust belt in the mountainous western one-third of Montana some 50 to 80 million years ago. Younger slip of a different direction along several faults in the Lewis and Clark zone has helped to shape the modern landscape through formation of valleys. However, most Lewis and Clark zone faults do not have documented Quaternary movement.

EARTHQUAKE EPICENTERS

Also depicted on the map are selected earthquake epicenters determined by the MBMG, which operates a network of seismograph stations in western Montana. Network data have been used to determine epicenters and magnitudes for over 14,000 earthquakes occurring from 1982 to 1998. Information about recent earthquakes is available through a link on the MBMG web site at <http://mbmgsun.mtech.edu>.

The number and proximity of seismometers that record an earthquake are the most important factors influencing the accuracy of an epicenter determination. Before 1995, seismograph network stations were generally limited to southwest Montana. Thus, the quality for epicentral locations of pre-1995 earthquakes in northwest Montana is generally below that for southwest Montana. For the same reason, many small northwest Montana earthquakes went undetected prior to 1995.

The quality of seismic monitoring in northwest Montana improved dramatically in 1995 when the MBMG entered into a cooperative agreement with the Confederated Kootenai and Salish Tribes (CSKT) in order to establish six seismographs on the Flathead Reservation, north of Missoula. Also in 1995, the MBMG received funding through a National Earthquake Hazards Reduction Program grant to install nine stations in west-central Montana between Helena and St. Regis. By 1998, the Montana seismograph network consisted of 31 seismographs distributed between Flathead Lake in northwest Montana and the north and west borders of Yellowstone National Park. Seismic data are recorded in Butte at the MBMG's Earthquake Studies Office (ESO), in Ronan at the CSKT Safety of Dams Office, and in Missoula at The University of Montana Geology Department. All seismic data are analyzed and archived in Butte. Additional data from seismographs operated by other agencies in surrounding states and Canada are routinely incorporated into Montana earthquake locations. Stickney (1995) described seismic instrumentation and data-analysis procedures employed in preparation of the Montana earthquake catalog.

A subset of 5,148 earthquake epicenters from western Montana was selected from the MBMG earthquake catalog and shown on this map. These selected earthquakes include all earthquakes with Richter magnitudes over 2.5 and those earthquakes of magnitude 1.5 or larger with better quality epicentral locations. Earthquake epicenters that lie more than 6 miles (10 km) outside the Montana border are not shown. The distribution of earthquake epicenters generally reflects the northern Intermountain Seismic Belt and eastern Centennial Tectonic Belt (Stickney and Bartholomew, 1987).

Star symbols show earthquakes of magnitude 5.5 or greater since 1900. The epicenter locations for historic Montana earthquakes are not as accurately determined as those after 1965 because prior to1965, few if any seismograph stations operated in Montana. Pre-1982 epicenters were taken from the National Oceanic and Atmospheric Administration hypocenter files, or later studies of these earthquakes if available.

EARTHQUAKE HYPOCENTERS

An earthquake hypocenter is the actual location of initial slip on a fault plane. This differs from the epicenter, which is the hypocenter projected vertically to the ground surface. Large earthquakes may have foreshocks, and many aftershocks follow, providing numerous hypocenter locations for imaging an active fault plane or fault zone. Mapping hypocenters in three-dimensions can provide information on orientation of the fault plane, relationship of the main shock to foreshocks and aftershocks, timing of movement on the three-dimensional fault plane, and discrimination between seismic events occurring on one well-defined fault plane versus multiple planes within a fault zone.

Hypocenter locations in three dimensions allow visualization of seismic events. The Norris earthquake swarm of 1987 offered an opportunity for MBMG to deploy field seismographs in the epicentral area to accurately measure aftershocks. Hypocenters were determined for nearly 600 events ranging from Richter magnitude –2.1 to 3.3. ArcView's 3D Analyst extension was used to visualize these well-constrained hypocenters.

Initial observations indicate that the aftershocks originated in a complex fault zone. The "cloud" of hypocenters could be interpreted as deep movement on the Bradley Creek fault, which has a scarp in this area, as well as other antithetic or synthetic faults at depth. As a first estimate, a planar regression was performed on all hypocenter locations. The resulting plane is a poor fit, with a Root Mean Squared (RMS) error of 618. The resulting plane, however, has a strike of N17W, a dip of 42° E, and would create a surficial trace on the DEM very close to the Bradley Creek fault scarp.

Assuming a planar fault surface, the location of the scarp itself also can be included to better constrain this potential fault plane. The arc associated with this fault trace was densified at 30 meters, resulting in 283 points. These points were assigned z values from the DEM, combined with the hypocenter points, and fitted to a second plane (figure 1). This plane was once again a poor fit, with an RMS value of 521. The new plane has a strike of

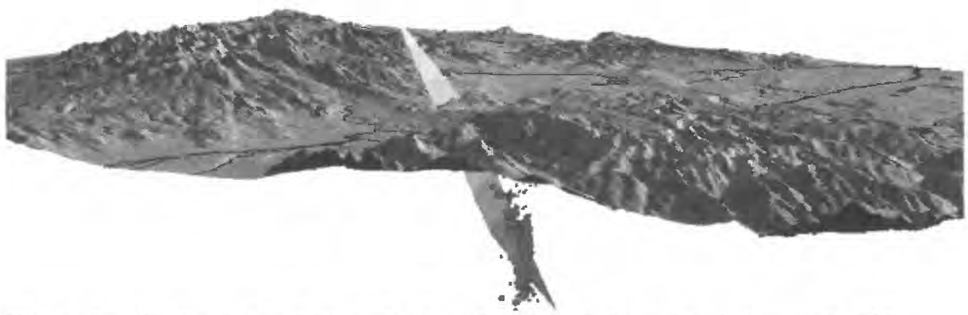

Figure 1. Norris earthquake best fit plane from regression analysis for nearly 600 hypocenter locations and 283 points located on the fault scarp.

N24W and a dip of 45° E. Results could be refined in several ways. The most obvious would be to divide the hypocenter data into different groupings, either by identifying multiple planes from visual inspection, or based on additional data such as first motion studies. In this manner, multiple fault planes could provide an overall better fit to all hypocenter and fault scarp data.

LINEAMENTS AND SEISMICITY IN EASTERN MONTANA

Lineaments

All magnitude 5.5 or greater earthquakes in Montana this century have occurred in the Intermountain Seismic Belt, except one - the May 16, 1909 earthquake in northeast Montana. Because of its early date, no local seismographs existed to record it; however, its widespread area of perceptibility and strong shaking near the epicenter suggest a magnitude of at least 5.5.

Identifying fault scarps in the less seismically active eastern half of Montana is challenging. One fault candidate is the Brockton-Froid lineament in northeastern Montana. The lineament has been interpreted by field mapping efforts of Colton (1963a) of the U.S. Geological Survey as a northeast-southwest (N55E) trending fault zone more than 50 km (30 mi) in length. The entire zone is straight, with the northeastern-most portion consisting of a single lineament. In the central portion, the zone consists of two parallel traces defining a small graben-like structure. At the southwestern end, the zone splays into several less well defined lineaments.

Vertical relief along the trend is evident in the Quaternary glacial till covering the area, implying relatively recent movement. Surficial deposits also vary across the inferred graben, changing from Quaternary alluvium outside the zone to Quaternary gravel within the inferred graben. Two traverses done with auger holes show thicker Quaternary sequences in the central graben as compared to outside of this structure (Colton, 1963b). No trenching has yet been done across the lineament.

The Brockton-Froid lineament is clearly identified from 30 m. Digital Elevation Models (DEMs) using analytical hillshading and remote sensing filtering techniques. Analytical hillshading applies a gray color to each pixel in the DEM based on the angle between the selected illumination vector and the surface normal vector. The illumination vector is defined by two angles, an attitude (compass direction between 0° and 360°) and an altitude (horizontal angle between 0° and 90°). The surface normal is a vector normal to a surface defined by a grid cell and its closest 8 neighboring grid cells. The grayness of grid cells will vary as a function of the cosine of the angle made in three dimensions between the surface normal and the illumination vector.

The Brockton-Froid lineament remains visible with large changes both in the attitude and altitude of the illumination vector. The ideal illumination direction would be at a right angle to the N55E trending zone. A hillshading of the DEM with an attitude of N35W and an altitude of 45° illuminates the lineament well (figure 2). Other examples of hillshading with large variations in attitude (+-60°) and altitude (+- 42°) produce an easily identified lineament. Only when the illumination direction is nearly parallel to the lineament (attitude = N55E) or when the illumination is vertical or horizontal (altitude = 0° or 90°) does the lineament disappear. The robustness of the lineament results from a laterally continuous trend which can readily be distinguished from the background. Efforts to find other lineaments in eastern Montana would require only a limited number of illumination vectors to cover all potential lineament orientations.

Filters are often used with remote sensing data to help define linear features present in imagery. Filters apply a small grid called a convolution kernel to each grid cell and neighboring grid cells. The values are then summed and divided by the number of grid cells in the kernel. The same techniques can be applied to gridded DEM data. Two filters were effective on this data, a filter to detect NE-SW oriented edges, and a filter to detect compass gradients. The best filter for detecting the Brockton-Froid lineament was the NW-oriented compass gradient filter. The kernel for this filter is designed to sum to zero in flat areas, sum to a positive number for NE-SW linear features increasing

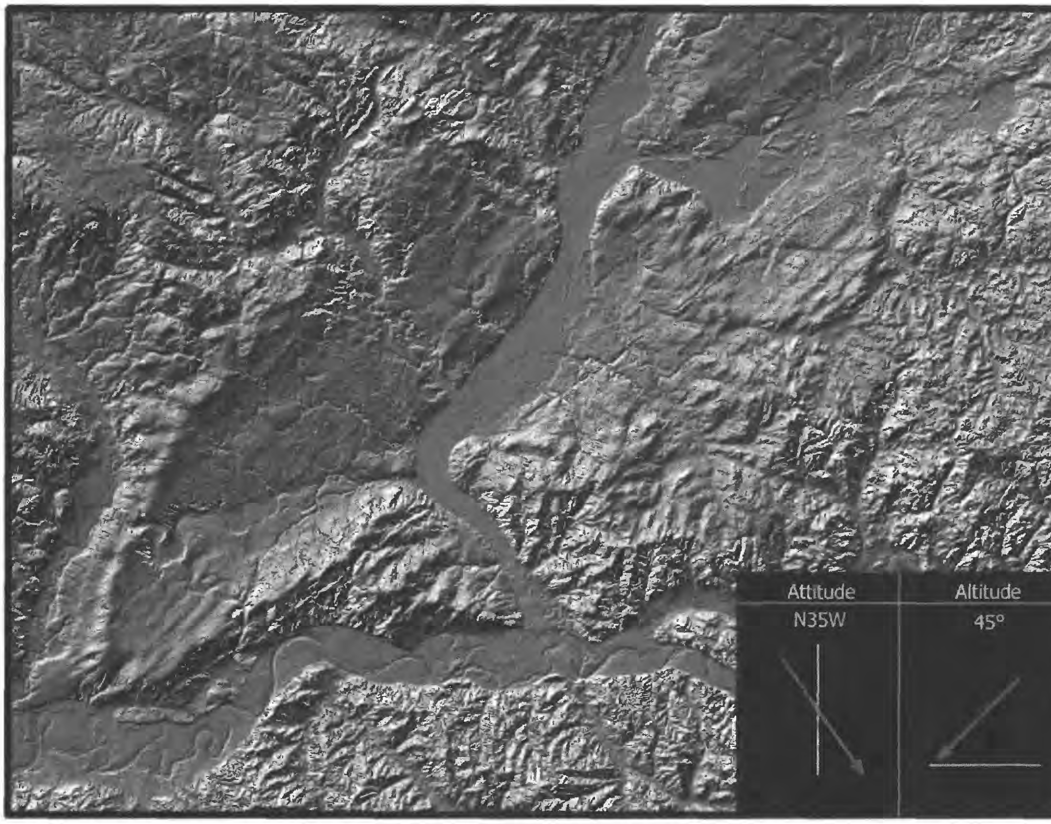

Figure 2. The Brockton-Froid lineament using analytical hillshading for visualization. The lineament is illuminated by a light source located at an azimuth of N35W and an angle from horizontal of 45°.

to the NW, and sum to a negative number for NE-SW linear features decreasing to the NW. This technique, however, produces a less visually continuous lineation than the analytical hillshading. The edge detection filter is not designed to sum to zero for flat areas; edges enhanced are overprinted on the topographic model. If, however, analytical hillshading is applied to the DEM after it undergoes NE-SW trending edge detection filtering, the result clearly shows the lineament. Although the lineament itself is no sharper than in traditional analytical hillshading, the filtering process eliminates other linear features not oriented NE-SW, allowing the lineament to stand out more clearly.

ACKNOWLEDGEMENTS

Funds to produce MBMG Special Publication 114, *Quaternary Faults and Seismicity Map of Western Montana* came from the Hazard Grant Mitigation Program administered by the Disaster and Emergency Services Division of the Montana Department of Military Affairs. Larry Akers and Jerry Smithers of DES were helpful in guiding us through the grant application process and program administration–their assistance is gratefully acknowledged. Richard Dart of the USGS supplied the digital fault data in ARC/INFO format. The MBMG Earthquake Studies Office, Confederated Salish and Kootenai Tribes' Safety of Dams Office, and the University of Montana Geology Department provided seismograph data for locating and cataloging western Montana earthquakes. The National Earthquake Hazards Reduction Program has provided two previous grants (awards 1434-94-G-2516 and 1424-95-G-2628) to the MBMG that expanded seismic monitoring capabilities and re-analysis of previously recorded earthquake data. Finally, thanks to GIS specialists Bill Myers and Paul Thale (MBMG) for GIS production of the map and cartographer Susan Smith (MBMG) for cartographic production.

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New Jersey and GIS, Perfect Together

By Zehdreh Allen-Lafayette

New Jersey Geological Survey
29 Arctic Parkway, CN 427
Trenton, New Jersey 08625
Telephone: (609) 292-2576
Fax: (609) 633-1004
e-mail: zehdreh@njgs.dep.state.nj.us

In 1835, the New Jersey Geological Survey (NJGS) was formed to provide a geological and mineralogical survey of the state. This was considered a temporary appointment that would end with the completion of the project. The Survey has been in active service to the State of New Jersey ever since, becoming "officially" permanent in 1864. Early published reports of geologic research resulted in etched plates containing hand drawn geologic layers and text brought together through a graphics technique called "paste-up". By the mid-1980's, the cartographic staff packed up their drafting pens in favor of high-end graphics computers.

To keep up with the thirty-two geologists, NJGS has a cartographic staff with a Section Chief and three full-time Geographic Information Systems Specialists. The Supervising Topographic Engineer spends the majority of his day working on report figures and designing and preparing reports for publication. The GIS Specialists are responsible for entering manuscript maps into the GIS, creating plates and figures from digital data for publication, and assisting and/or training other staff in the use of Arc/Info, ArcView, Pagemaker, Illustrator, and CorelDraw. Many of the geologists enter their own data into the GIS; some have enough experience with ArcInfo or ArcView to compose the Open-File plates that will be the final format of their research.

The maps displayed in this poster presentation represent a portion of the projects that have been incorporated into our digital data base. Many of these projects are available through Maps and Publications (Carroll Building, 428 East State Street, Trenton, NJ 08608, telephone: 609-777-1038, <http://www.state.nj.us/dep/njgs/pricelist/index.htm>) as hard copy or in digital format.

Digital Geologic Map Production at the North Carolina Geological Survey

By Jeffrey C. Reid, Michael A. Medina and Mark W. Carter

Division of Land Resources
North Carolina Geological Survey
1612 Mail Service Center
Raleigh, NC 27699-1612
Telephone: (919) 733-2423
Fax: (919) 733-0900
e-mail: Jeff.Reid@ncmail.net

GEOLOGIC MAP PRODUCTION

Geologic map production at the North Carolina Geological Survey (NCGS) increasingly uses MapInfo Professional 5.5 for digital geologic map preparation and layout.

Field sheets are digitized using GSMCAD (Williams, 1999). Files are imported into MapInfo as .dxf files. Digital raster graphic (DRG) 7.5-minute topographic maps provide the base; DRGs are projected to state plane coordinates or UTM coordinates in NAD27 or NAD83 projection. Paint Shop Pro (ver. 5.01) is used to remove the green overprint and to greyscale the DRGs. On-screen digitizing is becoming more commonly used.

Several 7.5-minute geologic maps in the Raleigh 1:100,000-scale sheet (a STATEMAP project area under the National Geologic Mapping Act) were created using MapInfo and released this year as NCGS Open-File Reports. Additional 1:100,000-scale county maps were created with MapInfo depicting active and inactive mine subsidence issues. These maps, also to be released as Open-File Reports, were designed to be used by county and city planning departments.

Digital orthophoto quarter quadrangles (DOQs) are used as a base in some projects. DRGs and DOQs are registered using WorldReg software. Geologic map symbols come from either GSMCAD (Williams, 1999) or in some cases from Geosymbol — a MapInfo add-on from Data Directions. Both programs are fully compatible with MapInfo software.

Shape files are produced as needed for users of ArcView. Files in other formats are produced as needed for clients.

Experiments in Geologic Map Production

The NCGS continues to experiment with several means of geologic map production. These experiments include: 1) using Mr. Sid technology on a map server to access the raster version of the state geologic map (NCGS, 1985) and generalized geologic map (NCGS, 1991) at the NCDOT's Travel and Tourism's Internet site: <http://204.211.241.138/sid/bin/index.plx?client= zReference\Geologic_Maps> and, 2) use of PDF files to produce camera-ready color printing pre-press and printer's color separations (Clark, 1999).

Map production is limited to paper. No digital geologic maps, other than the 1985 state geologic map (NCGS, 1985), are contained in the state's corporate database.

Issues in Geologic Map Production in North Carolina

Key issues in geologic map production in North Carolina are: 1) an estimated five-year production backlog of 7.5-minute geologic maps produced from 1968 to the present under the auspices of several cooperative mapping agreements with the Tennessee Valley Authority (TVA) and the USGS, including, most recently, STATEMAP, 2) geologic map production funding, and 3) metadata requirements. Additional resources will also be needed to digitally update the state geologic map (NCGS, 1985) which will soon go out-of-print. A related concern is the need for statewide vector hypsography.

Innovative techniques are being considered to relieve the backlog of TVA-era manuscript maps. These techniques have scanning and production of raster images as a common theme. Production may include CD-ROM venues using MapInfo Proviewer and PDF file formats.

North Carolina now requires that all digital maps, including geologic maps, be accompanied by metadata. In addition, complete metadata is required for a map to be included in the state's corporate database. Since many geologic maps consist of diverse base materials and, in many cases, the author is deceased or cannot be contacted, documentation of these maps is difficult. Thus, digital map production is slowed. Writing full FGDC compliant metadata may take almost as long as cartographic map production.

Image files (e.g. PDF, GIF and TIFF) formats are a temporary solution for dissemination on the Internet. However, these do not result in the digital geologic map data being collected, stored, and maintained in the state's corporate database. Provisional vector digital map layers, such as the 1985 state geologic map, are available on a mapping application site hosted by the Information Technology Services group of the Department of Environment and Natural Resources, and at the NC Center for Geographic Information and Analysis.

In North Carolina, the Freedom of Information Act requires that digital geologic information also be available in hard-copy format. Over the past several years, the North Carolina Geological Survey has explored methods to construct and publish geologic maps "in-house", yet retain the data in GIS-compatible formats. Our primary goals for map production are to reduce (1) the cost of printing highest-quality "traditional" maps, and (2) space (and cost)-consuming inventory.

One method employs GSMCAD 1.3, Adobe Illustrator 8, and MAPublisher 3.5. MAPublisher 3.5 is a suite of Plug-in GIS filters for Illustrator which was developed by Avenza Software (Muleme, 1999). This map production method is nearly identical to that currently in use by the USGS, Central Publications Group of the Geologic Division (Lane and others, 1999).

The procedure includes: (1) digitizing field-collected point and line data using a CalComp DrawingBoard III digitizing tablet and GSMCAD; (2) exporting the GSMCAD files as ArcView shapefiles (the ArcView shapefiles form the basis for both the final hard-copy map and the digital geologic dataset); (3) importing the shapefiles in Adobe Illustrator via MAPublisher to construct the traditional paper-printed map; and (4) printing the map in Illustrator format using either in-house equipment or a local blueprint shop. This process was used to reproduce a limited number of copies.

The high-end graphics capabilities of Illustrator allow for further cartographic editing of the geologic data, which is then merged with a 7.5-minute DRG topographic base (Adobe Photoshop 5.5 is used to convert the DRG to a grayscale bitmap or TIFF image) (Carter and Weiner, 1999). For smaller-scale maps such as county geologic maps (Carter and Merschat, in prep), a wholly vector-based base map can be constructed in Illustrator from hydrography and cultural (roadway and railroad networks) vector files available from the NCDOT or USGS. Ancillary geologic information, including cross sections, detailed rock unit descriptions, stratigraphic correlation diagrams, tabulated whole-rock geochemical data, references, etc. are constructed in Illustrator and incorporated into the map layout, which is limited only by the dimensions of the print media (typically 34" x 44").

In a small agency such as the NCGS, the field geologist is also typically the cartographer. This is advantageous because the map author is given tighter control over cartographic decision-making. It also allows for editing and interpretation of the geologic data throughout the map-making process—from field collection to final printing.

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Digital Geologic Mapping for the State Of Oklahoma

By T. Wayne Furr

Oklahoma Geological Survey
100 East Boyd Street, Room N-131
Norman, Oklahoma 73019-0628
Telephone: (405) 325-3031
Fax: (405) 325-7069
e-mail: twfurr@ou.edu

Since its beginning in 1993, the STATEMAP component of the National Cooperative Geologic Mapping Program has assisted the Oklahoma Geological Survey (OGS) in developing an ongoing geologic mapping program for the State of Oklahoma. To assist the OGS in establishing priorities of which areas of the State to map, the Oklahoma Geologic Mapping Advisory Committee (OGMAC) was formed. The OGMAC was established from representatives of State agencies, State planning associations, State industrial associations, and other organizations that have a Statewide perspective of geologic mapping needs in Oklahoma. Since its inception in 1993, the OGMAC has recommended two separate but related geologic mapping programs for the OGS to undertake.

The first program started in late 1994 when the OGMAC recommended that the OGS use digital technology to prepare a series of geologic maps at a scale of 1:100,000 for the entire State. The purpose of the maps is to provide a Geographical Information System geologic database of the State. In addition, the completed database would also provide the foundation for a new geologic map of Oklahoma, to be published at a scale of 1:500,000 (figure 1) (Suneson and Hemish, 1998).

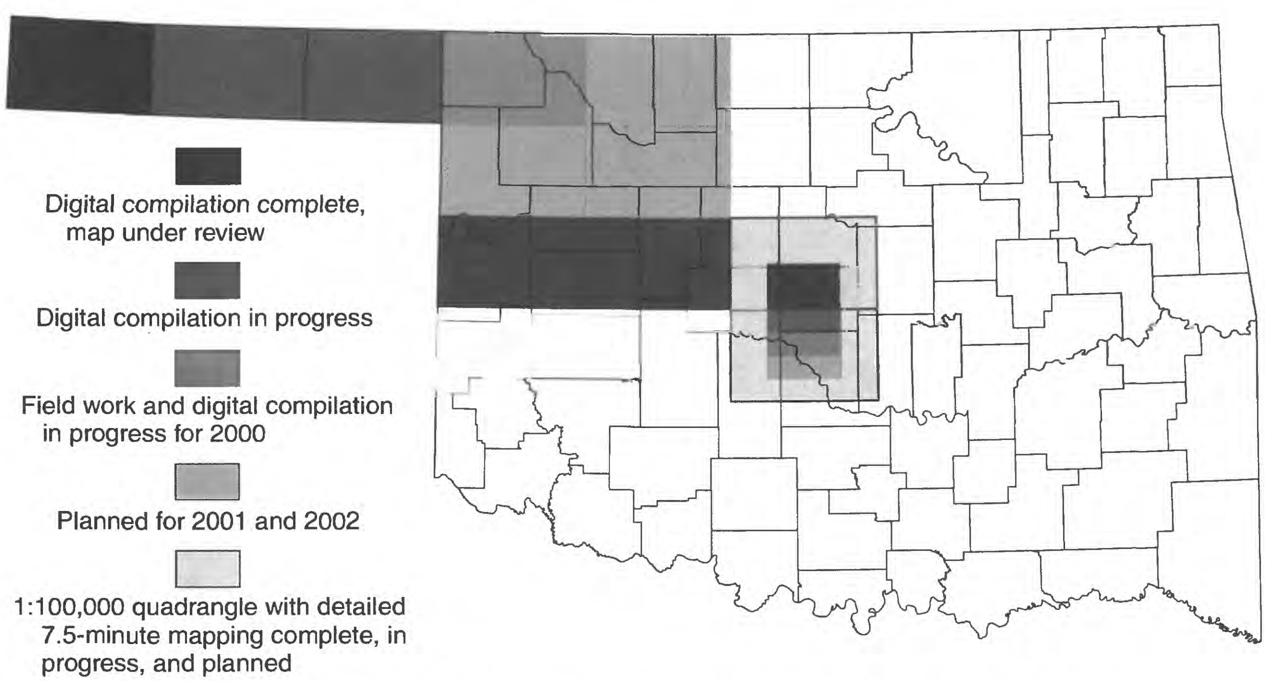

Figure 1. Status of the 1:100,000-scale digital geologic mapping program for the State of Oklahoma.

The second program is a continuation under STATEMAP of an older U.S. Geological Survey program called COGEOMAP, which was designed to provide detailed geologic maps and cross sections for areas that are of high-priority interest to federal and state agencies. At first, the OGS focused the STATEMAP mapping efforts in the Ouachita Mountains of eastern Oklahoma to complete the program that started in 1985 under the cooperative agreement between the OGS, the USGS, and the Arkansas Geological Commission (Johnson and Suneson, 1996).

In 1996, the STATEMAP program was shifted from the Ouachita Mountains when the OGMAC noted that no recent detailed geologic maps existed of the Oklahoma City Metro Area (OCMA). To remedy the problem, the OGMAC recommended a multi-year project of geologic mapping at a scale of 1:24,000. Their recommendation was based on the following factors:

(1) The OCMA is the most populous area in the State.
(2) OCMA is an area of rapid development.
(3) OCMA has major waste-disposal problems.
(4) There are increasing demands for local geological resources.
(5) There are hazardous-waste cleanup problems at Tinker Air Force Base.
(6) The city and eastern suburbs overlie a major aquifer that provides municipal drinking water.

Based on the OGMAC recommendation, the OGS in 1997 established a program to actively map the OCMA at a detailed scale (figure 2). The six-year project will cover 24 7.5'-quadrangle maps including all of Oklahoma City

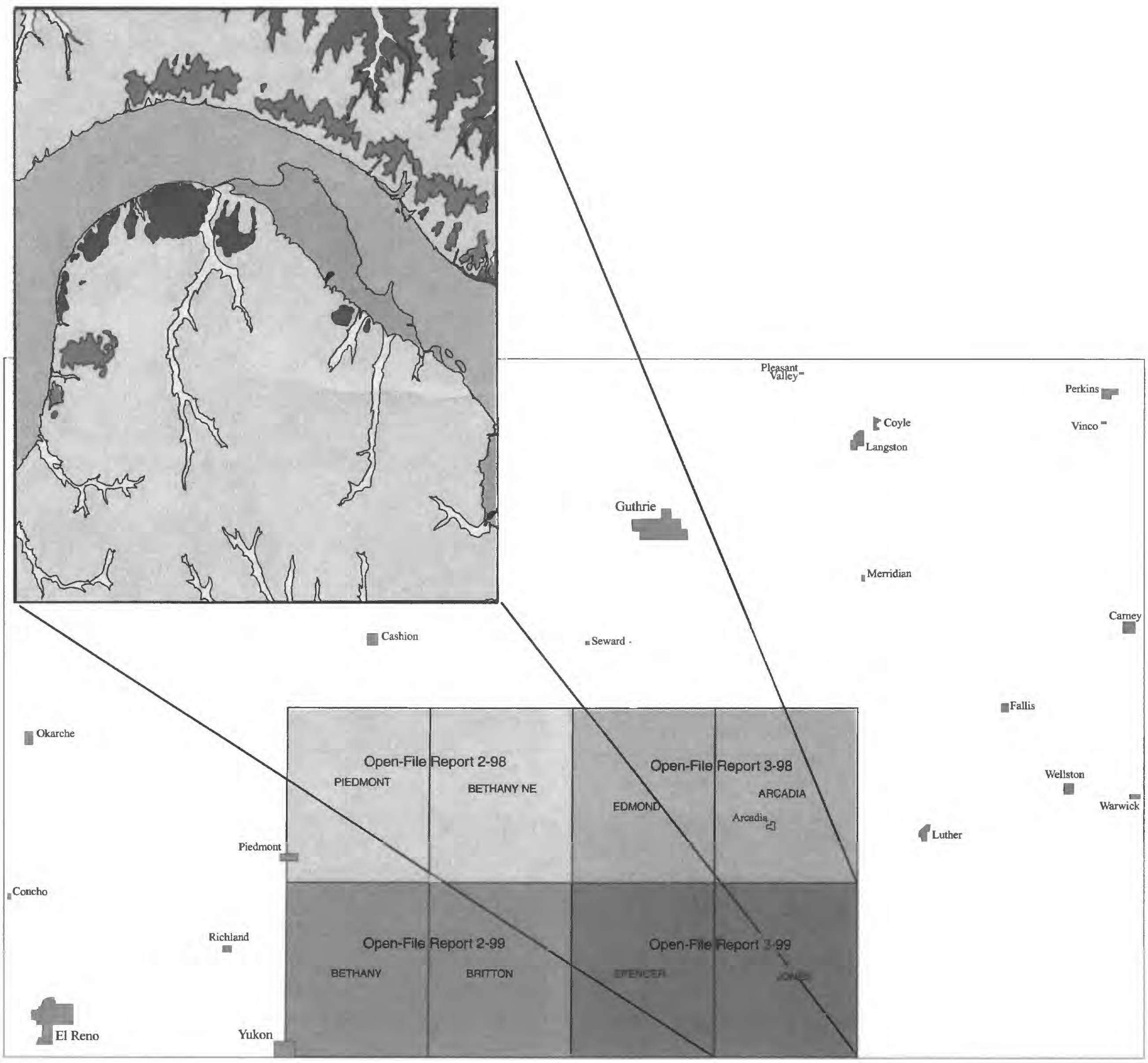

Figure 2. The Oklahoma City metro area surface-mapping program showing maps that have been released in the Oklahoma Geological Survey's Open-File Report series.

and most of the surrounding suburbs. The focus of the OCMA surface-mapping program is proper resource development and identification of potential engineering and environmental hazards. Concerns include protection of the Garber-Wellington aquifer, shrinking-clay soils in areas undergoing rapid development, present and future sand and gravel operations, potential landfill sites, and effects of past petroleum activities on the environment (Suneson and Hemish, 1998).

Completed maps for the former COGEOMAP and current STATEMAP programs are available as paper maps in the OGS Open-File Report series. Also, consideration is being given to digitizing the maps for future addition to the 1:100,000-scale digital map series. The eight quadrangles that are presently available for the OCMA update reconnaissance geologic work that is almost 50 years old. The following maps are currently available for the OCMA:

Piedmont-Bethany NE	OF 2-98	$4.80
Edmond-Arcadia	OF 3-98	$4.80
Bethany-Britton	OF 2-99	$5.20
Spencer-Jones	OF 3-99	$5.20

The Oklahoma Geological Survey produces this information as a service to the public, engineering firms, and municipal and county agencies in the State.

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Examples of Map Production at the Oregon Department of Geology and Mineral Industries

By Paul E. Staub and Mark E. Neuhaus

Oregon Department of Geology and Mineral Industries
800 N.E. Oregon Street
Portland, OR 97232
Telephone: (503) 731-4100
Fax: (503) 731-4066
http://sarvis.dogami.state.or.us/store/NatureNW.htm
e-mail: paul.staub@state.or.us

The cartography section of the Oregon Department of Geology and Mineral Industries (DOGAMI) prepares a variety of maps depicting the state's geology and geologic hazards. Maps are produced primarily using the MapInfo desktop GIS software. Certain components of the maps are created in MicroStation CAD before importing to MapInfo. MAPublisher is used for final preparation if a decision is made to output for offset printing. The decision to offset print versus inkjet print in-house hinges on the perceived level of demand. New inkjet printers with their higher speed and near-photo quality production are used for quantities of under 500. When a map is projected to have the potential for large demand, offset printing is used.

Examples included in this poster display with comments on production:

Geologic Map of the Summerville Quadrangle, Union County, Oregon

- the procedure adapted for production of this multi-color geologic map with a one bit, two color Digital Raster Graphic base was sparked by discussions at DMT '98. Maps are inkjet printed in-house.

Relative Earthquake Hazard Map of the Eugene-Springfield Metropolitan Area, Lane County, Oregon

- Polygonal data generated in MapInfo was taken into Freehand via MAPublisher. The shaded relief base was generated from 10 meter DEMs (from U.S. Geological Survey) in Vertical Mapper. Resulting files were delivered to an imagesetting service that provided color separated negatives for offset printing.

Tsunami Hazard Map of the Warrenton Quadrangle, Clatsop County, Oregon

- the production of this map series for the entire Oregon coast was mandated by the Oregon legislature as part of a public safety bill in 1995. Maps are inkjet printed in-house.

Tsunami Hazard Map of the Warrenton Area, Clatsop County, Oregon

- this study used base data with much higher resolution and the map is intended for evacuation planning. Maps are inkjet printed in-house.

Earthquake-Induced Slope Instability: Relative Hazard Map Eastern Portion of the Eola Hills, Polk County, Oregon

- this map was produced in MapInfo utilizing Vertical Mapper to do the grid-based analysis. Maps are inkjet printed in-house.

Water-Induced Landslide Hazards, Eastern Portion of the Eola Hills, Polk County, Oregon

- a contractor provided data in ArcView shape format, which were translated into MapInfo which was used to produce this map. Maps are inkjet printed in-house.

Earthquake Scenario Ground Shaking Map for the Portland, Oregon, Metropolitan Area: Portland Hills Fault M 6.8 Earthquake Peak Horizontal Acceleration (g) at the Ground Surface

- a cooperative project in which a private sector firm modeled various levels of ground shaking and produced PostScript files from ArcView. This map was offset printed.

An Easy Non-GIS Method for Making 3-D Digital Terrain Illustrations Using USGS 1:24,000- and 1:250,000-Scale Digital Elevation Models and Bryce4 Software

By F. Craig Brunstein, Alex Donatich, Carol A. Quesenberry, Nancy A. Shock, and Diane E. Lane

U.S. Geological Survey
Central Publications Group
Box 25046
Denver Federal Center, MS 902
Denver, CO 80225
Telephone: 303-236-5477
Fax: 303-236-6287
e-mail: cbrunste@usgs.gov

ABSTRACT

Three-dimensional (3-D) digital terrain illustrations offer the graphic designer and scientist an excellent way to portray certain geologic, geomorphic, tectonic, and topographic features for a range of scientific and popular publications. Making such illustrations has, until recent years, required the use of sophisticated GIS software, a steep learning curve, and much time and patience. A non-GIS software, Bryce4, used in conjunction with Adobe PhotoShop and Illustrator, provides graphic designers and scientists with an easy way to use USGS 1:24,000- and 1:250,000-scale Digital Elevation Models (DEM's) to make attractive 3-D terrain illustrations for use on the Web and in print and electronic publications. On this poster, we present the current status of non-GIS methods used in the USGS Central Publications Group to produce 3-D terrain illustrations for use in publications.

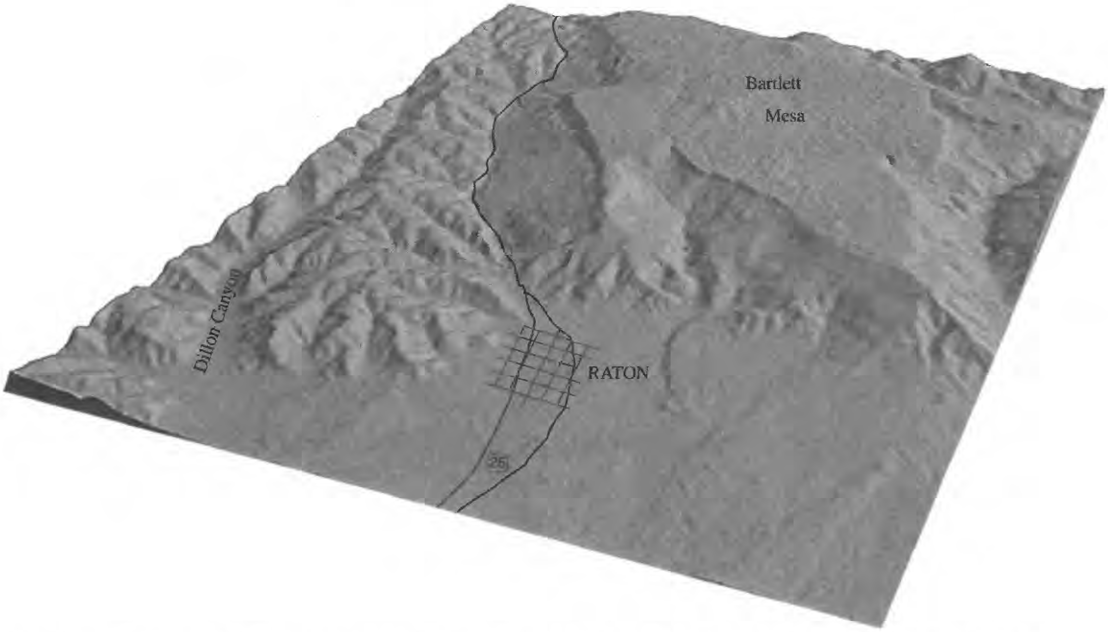
The poster presents a "cookbook" approach that includes all steps necessary to easily produce 3-D digital terrain illustrations. Toward that end, the poster reviews many of the steps discussed in Patterson (1998) and Sammis (1999). However, the poster presents additional information we think will be helpful to users, such as (1) how to maintain high resolution in 3-D terrain illustrations that will be used in print publications, (2) information on file formats and how to export 3-D images for further manipulation and corrections in Adobe PhotoShop and Illustrator, (3) information about tools in PhotoShop that are useful for manipulating colors and repairing imperfections in 3-D images exported from Bryce4, and (4) how to merge DEM's in Bryce4. The poster can be viewed and downloaded at URL <http://cpg.cr.usgs.gov/>.

SOFTWARE FOR MAKING 3-D TERRAIN ILLUSTRATIONS

Bryce4: (a PC- and Mac-compatible computer program by MetaCreations); for more information see URL <http://www.metacreations.com>.

MICRODEM/TerraBase II 4.0: (a PC-compatible computer program written by Peter Guth of the Oceanography Department, U.S. Naval Academy); can be downloaded free of charge at URL <http://www.usna.edu/Users/oceano/pguth/website/microdem.htm> [Note: at the present time, this software has the ability to make, manipulate, and display 3-D terrain images, but no capability is provided in the software to export such images for use in other programs.]

MacDem Beta-0.7: [a Mac-compatible computer program written by Jerry Farm (<macdemweb@treeswallow.com>)]; can be downloaded free of charge at URL <http://www.nacis.org/cp/cp28/resources.html> [Note: at the present time, this software has the ability to make, manipulate, and display 3-D terrain images, but we



Poster: Grayscale 3-D image of the Raton, New Mexico-Colorado, 1:24,000-scale quadrangle. North is to upper right.

are unsure of its capability to export such images for use in other programs.]

USGS WEB SITE FOR DOWNLOADING 1:24,000- AND 1:250,000-SCALE USGS DEM'S

<http://edc.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html>

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A Washington DC Area Geologic Map Database: Working Toward Implementation of the Digital Geologic Map Data Model

By Adam M. Davis, James Reddy, and C. Scott Southworth

U.S. Geological Survey
National Center, MS 908
12201 Sunrise Valley Drive
Reston, VA 20192
Telephone: (703) 648-6970
Fax: (703) 648-6937
e-mail: amdavis@usgs.gov

INTRODUCTION

Members of the National Geologic Map Database Project and the Eastern Earth Surface Processes Team of the United States Geological Survey (USGS) are collaborating to create a Washington D.C. area geologic map database (DCDB). This effort involves combining geologic map information from the following 30' X 60', 1:100,000-scale quadrangles (Figure 1):

- Frederick
- Washington West
- Fredericksburg
- Baltimore
- Washington East

The digital data for this project are derived from 1:100,000-scale geologic map compilations. For each map, the original field work was done at multiple scales. The database is being designed using Microsoft Access, but the GIS coverages are stored in ArcInfo coverage and ArcView shape file formats. The database aspires to meet the USGS Eastern Region information management and map production requirements, while at the same time conforming to the Digital Geologic Map Data Model (referred to as the "Data Model" throughout) that is currently being developed under the auspices of the North American Data Model Steering Committee (http://geology.usgs.gov/dm).

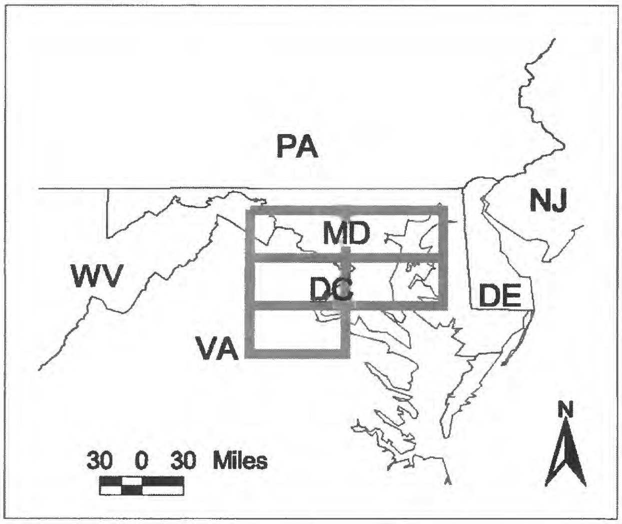

Figure 1. Map of the Washington, DC area, showing the five 1:100,000 scale 30' X 60' quadrangles that will initially be used for the Washington D.C. area geologic map database (DCDB).

IMPLEMENTATION OF THE DATA MODEL

The DCDB began as a set of Microsoft Access tables that contained columns (fields) for each of the data elements that the Eastern Earth Surface Processes Team collect and want to associate with their digital spatial data. Currently, the DCDB is in the process of being transformed into a format compliant with the Data Model, but in its present form is significantly different from the Data Model.

For the most part, the data fields of the DCDB each have a direct equivalent in the Data Model. However, the DCDB does have some fields and tables for which the Data Model does not contain an equivalent. For example, the DCDB contains a table dedicated to clast information and another dedicated to mineral information (for entire formations), neither of which have an exact equivalent table or even fields in the Data Model. Also, the DCDB stores geochronologic information associated with points separate from geochronologic information associated with formations or igneous bodies (i.e., there are two data tables for the different types of geochronologic information in the DCDB).

In addition, there are aspects of the Data Model that are not yet implemented or are implemented to a lesser extent in the DCDB. For example, the DCDB does not yet contain any metadata. Also, cartographic specifications are included in ArcInfo attribute tables and are not as extensive as those specified in the "legend" portion of the Data Model (Johnson and others, 1998).

The DCDB is also structured differently than the Data Model. Figure 2 is a relationships diagram that illustrates the current structure of the DCDB. In this figure, fields are marked that exist in the DCDB but do not have an identical match in the Data Model. Note that most relationships between tables are routed through the MAP_UNIT table. The MAP_UNIT field is used for relating many of the other data elements, similar to the COA_ID in the data model.

ISSUES ENCOUNTERED

As the Washington D.C. Area database effort progresses, we are addressing issues associated with implementing the Data Model. These issues relate to software, GIS, data storage, and data elements. Some issues are:

- Geologists record data elements not accounted for in the data model (e.g., they collect clast information and record which deformational event is associated with a rock unit's formation [e.g., Acadian Orogeny]),
- Geologists record data in such a way that it does not exactly fit the fields in the Data Model (e.g., recording primary and secondary minerals for the whole formation rather than for a lithology). As a result, table structure and names of fields may need to be different from that of the Data Model to maximize efficiency of data storage and use (e.g., the DCDB requires a "minerals" table in addition to a "lithology" table). Differences in the amount of normalization of the data may also be required,
- Database designers need to work with the field geologists in order to construct data entry tools and views for analysis,
- ArcInfo file structure governs parts of the database structure. Spatial data is stored in tables separate from

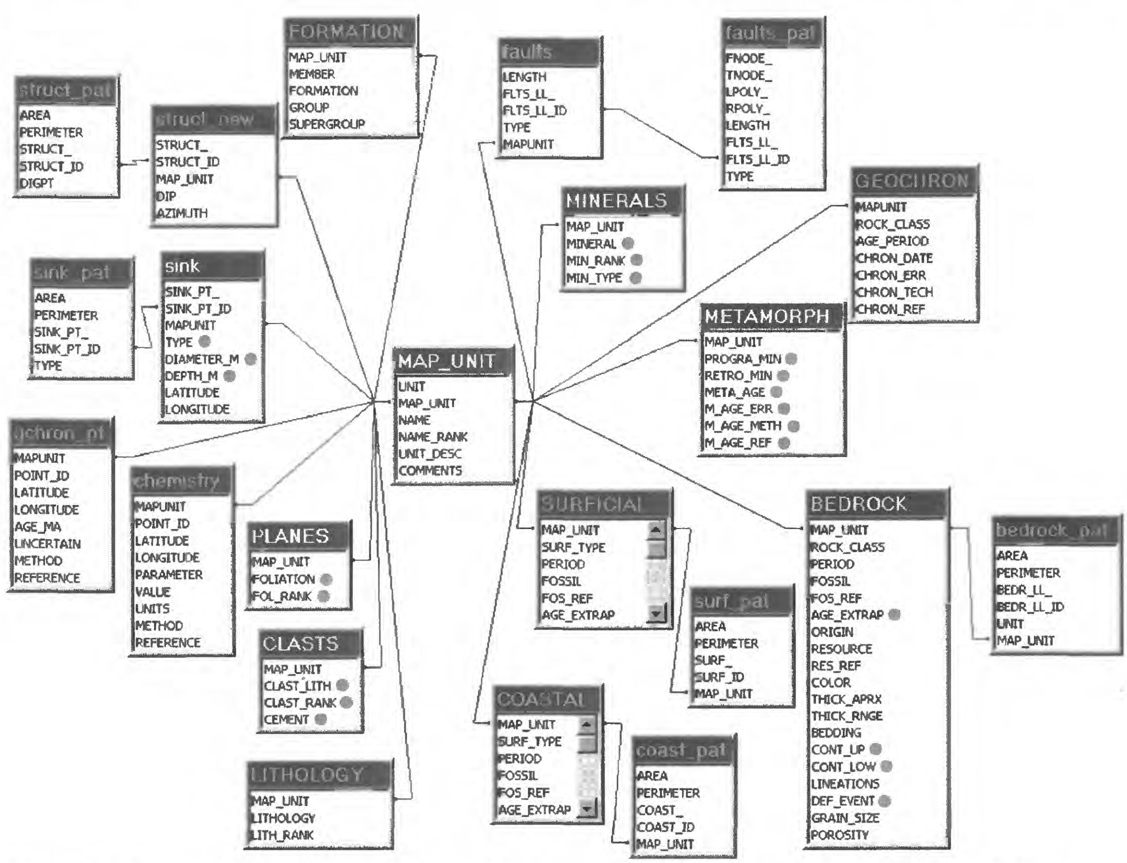

Figure 2. Diagram illustrating the relationships between data elements of the Washington D.C. area geologic map database (DCDB). Data fields which do not have exact matches in the Data Model are marked with gray circles.

their associated attribute data. Forming "joins" between these spatial data tables and other tables must be done through the ArcInfo attribute tables,
- Use of two software packages, ArcInfo (or ArcView) and MS Access, limits data storage and retrieval efficiency, because the two software packages must connect with one another through an ODBC driver,
- Problems with "edge-matching" of GIS coverages, including:
  - Lithologic contacts offset at quadrangle boundaries
  - Formation names inconsistent between quadrangles
  - Formations divided into members in one quadrangle and not the other
  - Geologists having different field interpretations
  - Field work and cartography done at different times
  - Different portions of the field work done at different times.

NEXT STEPS

Resolution of some of the issues mentioned above may require that fields be added to existing tables in the data model (e.g., the metamorphic table may need more fields). In other cases, entire tables may need to be added (e.g., clast information, and mineral information for whole formations versus individual lithologies).

Working with the geologists and analysts who will be using the database is another significant challenge for this implementation of the Data Model. The appearance of the data entry forms and views of the data will have to be compatible with the people using them. Normalized data tables can appear unfamiliar to geologists who commonly view tabular data in spreadsheet or other formats (similar to problems occurring between databases and analysts in other professions). "Queries" or "Views", depending on the database software, can be created to alleviate this problem, but complexity of the database and/or the data viewing client software increases as these "Views" and "Queries" must be stored and maintained.

In the interest of optimizing the data storage, retrieval, and analysis efficiencies of the database, the DCDB project may need to move away from its current software choice of Microsoft Access and ArcInfo (or ArcView). The project aspires to port (convert) the database into a single software or at least a more integrated software solution. After working through some of the issues mentioned in this paper, we hope to have a good prototype database that can be used as a building block for the National Geologic Map Database.

REFERENCE

Johnson, B.R., Brodaric, B., Raines, G.L., Hastings, J.T., and Wahl, R., 1998, Digital Geologic Map Data Model Addendum to Chapter 2 – Version 4.3: <http://geology.usgs.gov/dm>

APPENDIX A

List of Workshop Attendees

[Grouped by affiliation]

Alaska Geological & Geophysical Survey
Gina Graham

Arizona Geological Survey
Stephen M. Richard

California Division of Mines & Geology
David L. Wagner

Delaware Geological Survey
Lillian Wang

Environmental Systems Research Institute
Mike Price

Geological Survey of Alabama
April Lafferty
Berry H. Tew

Geological Survey of Canada
Eric Boisvert
Boyan Brodaric
Peter Davenport

Hewlett Packard
John DiTomasso

Idaho Geological Survey
Jane S. Freed
Tim Funderburg
Loudon Stanford

Illinois Geological Survey
Curtis Abert
Sheena Beaverson
Robert Krumm

Indiana Geological Survey
Richard T. Hill
Paul Irwin
Kim Sowder

Kansas Geological Survey
David R. Collins
Elizabeth Crouse
Jorgina A. Ross

Kentucky Geological Survey
Warren Anderson
James C. Cobb
Doug Curl
James Drahovzal
Shawn Duncan
John D. Kiefer
Steve Martin
Michael Murphy
Richard Sergeant
Mike Solis
Thomas Sparks
Mark Thompson

Louisiana Geological Survey
Richard P. McCulloh
R. Hampton Peele

Minnesota Geological Survey
Joyce Meints

Missouri Department of Natural Resources
Mark A. Middendorf

Montana Bureau of Mines & Geology
Patrick Kennelly
Susan M. Smith

National Park Service
Tim Connors
Ron Cornelius
Steve Fryer

Natural Resources Canada
Vic Dohar
Dave Everett

New Jersey Geological Survey
Zehdreh Allen-Lafayette

New Mexico Bureau of Mines & Mineral Resources
Kathy Glesener
David J. McCraw

North Carolina Geological Survey
Jeffrey C. Reid

North Dakota Geological Survey
Ryan Waldkirch

National States Geographic Information Council
Susan Carson Lambert

Nevada Bureau of Mines & Geology
Robert Chaney

Ohio Geological Survey
Thomas M. Berg
Edward V. Kuehnle
James McDonald

Oklahoma Geological Survey
T. Wayne Furr

Oregon Department of Geology & Mineral Industries
Mark Neuhaus
Paul E. Staub

Pennsylvania Geological Survey
Gale Blackmer
William E. Kochanov
Christine E. Miles
Caron O'Neil
Thomas G. Whitfield

Smallworld Systems Inc.
Robert P. Laudati

South Carolina Geological Survey
C. Scott Howard

Techni Graphic Systems
James Chappell
Robinson S. Noble
Steve Yeldell

Tennessee Division of Geology
Elaine Foust

University of Alabama
Douglas Behm

University of Minnesota
Paul Morin

University of Nebraska
Hannan LaGarry

U.S. Forest Service
Andrew Rorick

U.S. Geological Survey
Bruce Bauch
Darlene A. Casebier
Adam Davis
James D. Hoffman
Bruce R. Johnson
Elizabeth D. Koozmin
Diane E. Lane
Jonathan C. Matti
Michele McRae
Kathryn Nimz
Randall Schumann
Peter Schweitzer
Nancy A. Shock
David R. Soller
Nancy Stamm
Ronald R. Wahl
Bruce Wardlaw

Utah Geological Survey
Kent D. Brown

Virginia Geological Survey
Ian Duncan
Nick Evans

Wisconsin Geological Survey
Bill Bristoll
Michael L. Czechanski
Chip Hankley
Mindy James

APPENDIX B
Workshop Web Site

Digital Mapping Techniques '00

Association of American State Geologists — United States Geological Survey

Convened by the Association of American State Geologists and the U.S. Geological Survey
Hosted by the
Kentucky Geological Survey
May 17-20, 2000
Lexington, Kentucky

The Workshop on Digital Mapping Techniques (DMT '00) is an invitation-only event designed to bring together workers at State and Federal agencies who are creating digital geologic maps of the United States. Topics will focus on methods of data capture, 3-D data visualization, managing geologic maps in a proposed standard data model, digital map production, and progress toward building a National Geologic Map Database.

**Note: Many of these pages are still under construction, so check back often!*

About the workshop

- Online registration form -*All registrants should fill out this online form, even if you submit a mail-in/fax registration form for credit card or other purposes.*
- Mail in/fax registration form
- Recommended lodging
- Workshop site information / maps
- Guidelines for paper submissions with paper templates
- Poster specifications
- Schedule of events
- List of attendees

Lexington Information:

Lexington-Fayette Urban County Government

Kentucky Geological Survey — Proposed N. American Geologic Data Model

National Geologic Map Database — Association of American State Geologists

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]

3SpaceAssistant - Template Graphics Software Inc., 5330 Carroll Canyon Road., Suite 201, San Diego, CA 92121-3758, (800) 544-4847, <http://www.tgs.com>.

Adobe Illustrator 8.0, Photoshop 5.5, Acrobat, and Acrobat Reader - Adobe Systems Inc., 345 Park Avenue, San Jose, CA 95110-2704, (800) 833-6687, <http://www.adobe.com>.

ArcInfo, ArcView, ArcExplorer, MapObjects, and ArcPad - Environmental Systems Research Institute Inc. , 380 New York St., Redlands, CA 92373-8100, (714) 793-2853, <http://www.esri.com>.

Asus - Asus Inc., 150 Li-Te Road, Peitou, Taipei, Taiwan 112 R.O.C., +886-2 2894-3447, <http://www.asus.com/>.

AutoPlay Menu Studio Professional - Indigo Rose Corporation, 123 Bannatyne Ave., Suite 230, Winnipeg, MB, Canada R3B 0R3, (800) 665-9668, <http://www.indigorose.com>.

AVS Visualization Software - Advanced Visual Systems Inc., 300 Fifth Avenue, Waltham, MA 02451, (781) 890-4300, <http://www.avs.com/>.

Base Imager, GEOVEC, MGE - Intergraph Corporation, Corporate Headquarters, Huntsville, AL 35894-0001, (256) 730-2000, <http://www.intergraph.com/dynamicdefault.asp>.

Brick of Bytes (BOB) - Graphics and Visualization Lab, Army High Performance Computing Research Center, Network Computing Services Inc., 1200 Washington Avenue South, Minneapolis, MN 55415, (612) 337-3550, email: elyce@ networkcs.com, <http://www.arc.umn.edu/gvl-software/bob.html>.

CalComp Digitizing Equipment - GTCO CalComp Inc., 14555 N. 82nd Street, Scottsdale, AZ 85260, (800) 458-5888, <http://www.gtcocalcomp.com>.

CAVE Guide - Electronic Visualization Laboratory, University of Illinois at Chicago, 851 S. Morgan St., Room 1120, Chicago, IL 60607-7053, (312) 996-3002, email: cavesupport@evl.uic.edu, <http://www.evl.uic.edu/pape/CAVE/prog/CAVEGuide.html>.

Cold Fusion - Allaire Corporation, 275 Grove Street, Newton, MA 02466, (888) 939-2545, email: info@allaire.com, <http://www.allaire.com>.

Compaq - Compaq Computer Corporation, 20555 SH 249, Houston, Texas 77070-2698, (800) 888-0220 <http://www.compaq.com>.

CosmoPlayer - Computer Associates International, Inc., One Computer Associates Plaza, Islandia, NY 11749, (631) 342-5224, <http://www.cosmosoftware.com/>.

Data Directions - Data Directions, 4560 Fox Hollow Rd., Eugene, OR 97405, (541) 345-4MAP, <http://hometown.aol.com/mapdata>.

Delphi - Inprise Corporation, Worldwide Headquarters, 100 Enterprise Way, Scotts Valley, CA 95066, (831) 431-1000, <http://www.inprise.com/delphi>.

DemoShield Software - InstallShield Software Corporation, 900 National Parkway, Suite 125 Schaumburg, Illinois 60173-5108, (847) 240-9111, <http://www.installshield.com>.

EarthVision - Dynamic Graphics Inc., 1015 Atlantic Avenue, Alameda, CA 94501-1154, (510) 522-0700, <http://www.dgi.com>.

Elsa Erazor X - Elsa Inc., 1630 Zanker Rd., San Jose, CA 95112, (408) 961-4600, <http://www.elsa.com/>.

Epson 3000 printers - Epson America Inc., 3840 Kilroy Airport Way, Long Beach, CA 90806, (800) 873-7766, <http://www.epson.com>.

Fakespace - Fakespace Systems Inc., 809 Wellington St., N., Kitchener, ON, Canada N2G 4J6, (519) 749-3339, <http://www.fakespacesystems.com>.

FieldLog - <http://gis.nrcan.gc.ca/fieldlog/Fieldlog.html>.

FieldWorker - Fieldworker Products Ltd., 551 Millwood Road, Toronto, ON, Canada M4S 1K7, (416) 483-3485, <http://www.fieldworker.com>.

Freehand - Macromedia Inc., 600 Townsend St., San Francisco, CA 94103, (800) 457-1774, <http://www.macromedia.com/software/freehand/>.

GeoExplorer3 - Trimble, 645 North Mary Avenue, Sunnyvale, CA 94086, (800) 545-8389, <http://www.trimble.com>.

GeoMapper - Earth Resources Center Digital Mapping Lab, 365 McCone Hall, University of California Berkeley, Berkeley, CA 94720-4767, (510) 642-5868, email: <brimhall@socrates.berkeley.edu>.

GS50 - Leica Geosystems Inc., 4855 Peachtree Industrial Blvd., Suite 235, Norcross, GA 30092, (800) 367-9453, <http://www.leica-geosystems.com>.

HP Large-format Plotters - Hewlett-Packard, 3000 Hanover Street, Palo Alto, CA 94304-1185, (650) 857-1501, <http://www.hp.com>.

IBM Open Data Explorer - IBM North America, 1133 Westchester Avenue, White Plains, NY 10604, (404) 238-1234, email: askibm@vnet.ibm.com, <http://www.research.ibm.com/dx/>.

Iris Explorer - NAG LTD, Wilkinson House, Jordan Hill Road, OXFORD, OX2 8DR, UK, +44 1865 511245, <http://www.nag.com/Welcome_IEC.html>.

MapGuide, DXF (Drawing Exchange Format), and Autodesk OnSite View - Autodesk Inc., 111 McInnis Parkway, San Rafael, CA 94903 USA, (800) 538-6401, <http://www3.autodesk.com>.

MapInfo - MapInfo Corporation, One Global View, Troy, NY 12180, (800) 327-8627, <http://www.mapinfo.com/>.

MAPublisher - Avenza Software Inc., 6505-B Mississauga Road, Mississauga, ON, Canada L5N 1A6, (800) 884-2555, email: info@avenza.com, <http://www.avenza.com>.

Microstation - Bentley Systems Inc., 685 Stockton Drive, Exton, PA 19341-0678, (800) 236-8539, <http://www.bentley.com>.

Mr Sid - LizardTech Inc., The National Building, Second Floor, 1008 Western Avenue, Seattle, WA 98104, (206) 652-5211, <http://www.lizardtech.com>.

Oracle - Oracle Corporation, 500 Oracle Parkway, Redwood Shores, CA 94065, (800) 672-2531, <http://www.oracle.com>.

Paintshop Pro - Jasc Software Inc., 7905 Fuller Road, Eden Prairie, MN 55344, (800) 616-3255, <http://www.paintshoppro.com>.

Palm OS - Palm Inc., 5470 Great America Pkwy, Santa Clara, CA 95052, (800) 881-7256, <http://www.palm.com/home.html>.

PenMap, Panasonic CF-M33, Fujitsu, Via, Vectormap, Digital Reconnaissance Set, The Full Monty - Condor Earth Technologies Inc., 21663 Brian Lane, Sonora, CA 95370-3905, (209) 532-0361, <http://www.condorearth.com/products>.

Postershop - Onyx Graphics Corporation, 6915 S. Hightech Drive, Midvale, UT 84047-3757, (800) 828-0723, <http://www.onyxgfx.com>.

Silicon Graphics - Silicon Graphics Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043, (650) 960-1980, <http://www.sgi.com>.

Smallworld — Smallworld Systems, Inc. (U.S. Office), 5600 Greenwood Plaza Blvd., Suite 300, Englewood, CO 80111, (303) 779-6980, <http://www.swldy.com>.

Solo CE - Tripod Data Systems, 345 Southwest Avery Ave., Corvallis, OR 97339, (541) 753-9322, <http://www.tdsway.com/products/index.html#solo>.

SPARC - Space Physics and Aeronomy Research Collaboratory, <http://intel.si.umich.edu/SPARC/>.

Stereo3D.com - <http://www.stereo3d.com/>.

Sun - Sun Microsystems Inc., 901 San Antonio Road, Palo Alto, CA 94303-4900, (650) 960-1300, <http://www.sun.com>.

Vertical Mapper - Northwood Technologies Inc., 43 Auriga Drive, Nepean, Ontario, K2E 7Y8, (888) 886-0381, <http://www.northwoodgeo.com/>.

Visual Basic, Visual Basic for Applications, and Windows 95/98/NT/2000 - Microsoft Corp., One Microsoft Way, Redmond, WA 98052-6399, (425) 882-8080, <http://www.microsoft.com>.

Web3D Consortium - Web3D Consortium Inc., c/o Interprise Ventures, Bishop Ranch 2, 2694 Bishop Drive, Suite 105, San Ramon, CA 94583, (925) 277-8110, <http://www.web3d.org/>.

WebTrends Enterprise Suite - WebTrends Corporation Headquarters, 851 SW 6th Avenue, Suite 1200, Portland, Oregon, 97204, (503) 294-7025, <http://www.WebTrends.com>.

World Construction Set - 3D Nature, LLC., 5740 Olde Wadsworth, Suite C, Arvada, CO 80002, (303) 659-4028, <http://www.3dnature.com>.

ZEH - ZEH Software Inc., 1155 Dairy Ashford, Suite 105, Houston, Texas 77079, (281) 589-7757 <http://www.zeh.com>.

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