Vol. 6, No. 3 March 1996

GSA TODAY

A Publication of the Geological Society of America

INSIDE

Development of Geographic Information Systems–Oriented Databases for Integrated Geological and Geophysical Applications

J. Douglas Walker, Ross A. Black, Jonathan K. Linn, *Department of Geology, University of Kansas, Lawrence, KS 66045*

A. J. Thomas, R. Wiseman, M. G. D'Attilio, *Department of Geography, University of Kansas, Lawrence, KS 66045*

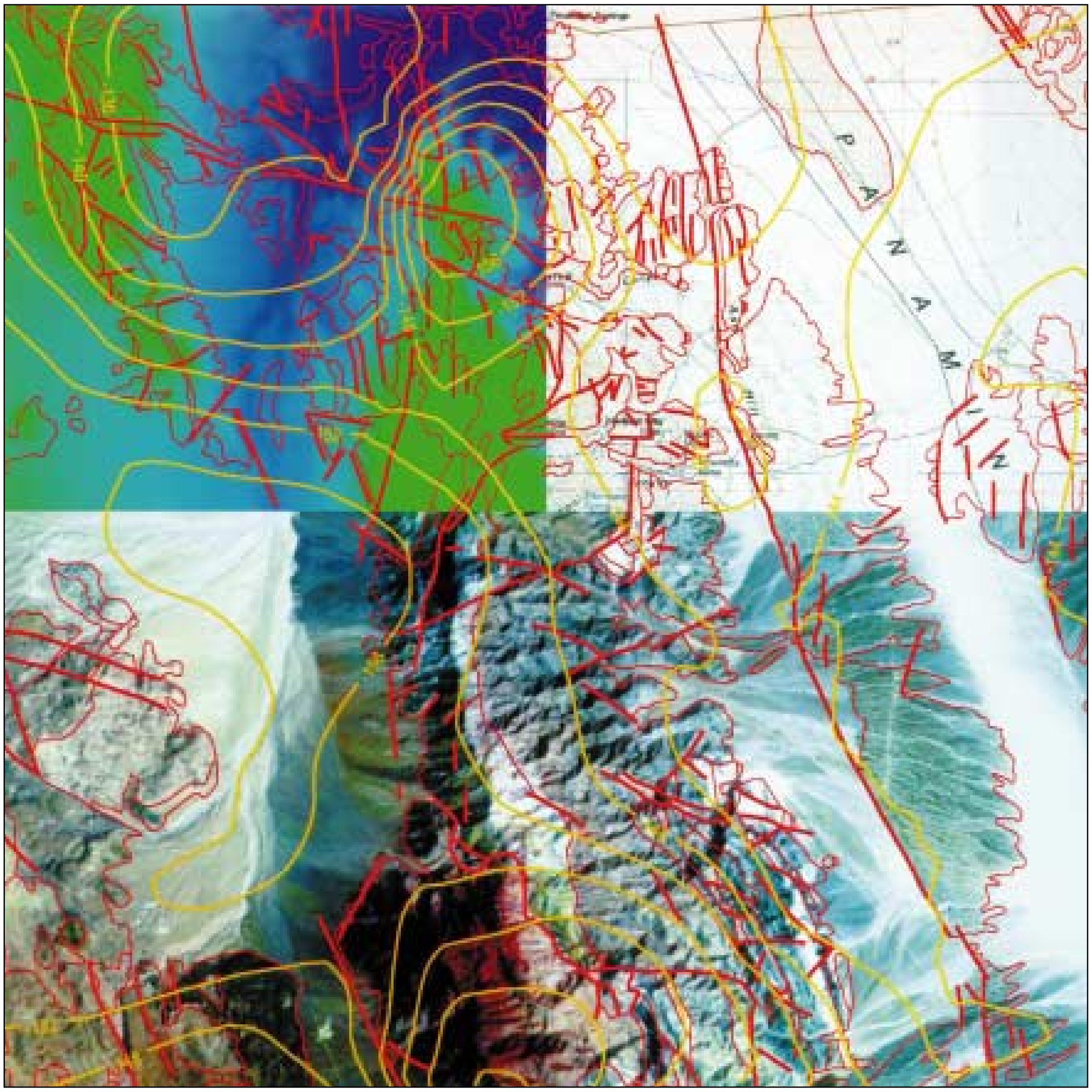

Figure 1. Composite satellite imagery, geologic contact, digital elevation model and gravity map of the Maturango Peak–Panamint Springs area, Argus Range and Panamint Valley, California. The map base is built from various contiguous image sources: lower half—16.5 m pixel thematic mapper image; upper left—15 m pixel digital elevation models (northwest corner); and upper right—part of the Darwin 1:100,000 sheet. Colors on the elevation model ramp from about 450 m for the darkest blue to about 1800 m for the brightest green. Overlain on this are geologic contacts (bold red lines representing faults, thin red lines showing depositional and intrusive contacts) from Moore (1976). The orange lines are Bouguer gravity contours in mgal from the National Geophysical Data Center data set. The area shown is approximately 30 km × 30 km.

ABSTRACT

The use of geographic information systems (GIS) is becoming increasingly common in geological and geophysical studies. These systems provide powerful tools for integrating and analyzing large data sets of various kinds and origins. One of the most complex and costly data sets to incorporate into these systems is surface geological information (geologic maps), which require intense and time-consuming effort to digitize, characterize, and check for quality. If entered thoroughly, that is with each geologic contact, rock unit, and structural measurement recorded and assigned explicit geologic attributes, the resulting data set is accessible to both casual and expert users. In addition, the attributes allow for detailed analysis of the geology. Other types of data—e.g., gravity measurements and earthquake foci—either are available free of charge or can be purchased at a small cost. These data sets are typically already in a form easy to integrate into a GIS database. When properly constructed, the final database contains a variety of types of information that are referenced to a common geographic base.

Databases *continued on p. 2*

GSA TODAY

March 1996
Vol. 6, No. 3

GSA TODAY (ISSN 1052-5173) is published monthly by The Geological Society of America, Inc., with offices at 3300 Penrose Place, Boulder, Colorado. Mailing address: P.O. Box 9140, Boulder, CO 80301-9140, U.S.A. Second-class postage paid at Boulder, Colorado, and at additional mailing offices. **Postmaster:** Send address changes to *GSA Today,* Membership Services, P.O. Box 9140, Boulder, CO 80301-9140.

SUBSCRIPTIONS for 1996 calendar year: **Society Members:** *GSA Today* is provided as part of membership dues. Contact Membership Services at (800) 472-1988 or (303) 447-2020 for membership information. **Nonmembers & Institutions:** Free with paid subscription to both *GSA Bulletin* and *Geology,* otherwise $45 for U.S., Canada, and Mexico; $55 elsewhere. Contact Subscription Services. **Single copies** may be ordered from Publication Sales. **Claims:** For nonreceipt or for damaged copies, members contact Membership Services; all others contact Subscription Services. Claims are honored for one year; please allow sufficient delivery time for overseas copies.

Issues of this publication are available electronically, in full color, from GSA as Acrobat "Portable Document Format" (PDF) files. These can be viewed and printed on personal computers using MSDOS or MSWindows, on Macintoshes, or on Unix machines. You must use the appropriate Adobe Acrobat Reader, available for free download from GSA and other online services. The more powerful Adobe Exchange program, available from commercial software suppliers, may also be used. Download the issues of *GSA Today* and/or the appropriate Readers using the Uniform Resource Locator (URL): http://www.geosociety.org. Issues of *GSA Today* are posted about the first of the month of publication.

This publication is included on GSA's annual CD-ROM *GSA Journals on Compact Disc.* Call GSA Publication Sales for details.

Printed with pure soy inks on recyclable paper in the U.S.A.

IN THIS ISSUE

Databases *continued from p. 1*

INTRODUCTION

Geographic information systems (GIS) are being used by thousands of companies, government agencies, and other entities worldwide for the storage, retrieval, and manipulation of spatially referenced data. Several groups, such as the U.S. Geological Survey (USGS), work specifically with geological information (e.g., Wright and Stewart, 1990; Wentworth and Fitzgibbon, 1991; Fitzgibbon et al., 1991; Jacobson, 1993) and have put together techniques for handling such data sets. At the University of Kansas we have recently put together a GIS laboratory specifically for performing integrated geological and geophysical studies. We use the programs ARC/INFO™ (by Environmental Systems Research Institute, Inc.) for GIS generation and IMAGINE™ (by ERDAS, Inc.) for manipulating imagery data.

The usefulness of a GIS can be demonstrated in the following scenario. For a mapping project, a geologist usually starts out by examining a small-scale, regional geologic map (e.g., a state map) to pick a study area. Mapping is then done using 1:24,000 or larger scale topographic maps or air photos. The data are then compiled on topographic maps, possibly at another map scale, either by directly tracing on an overlay sheet or by visually transferring data by using topographic features. The geologist may also utilize a Landsat Thematic Mapper scene that shows important features that can be related to the compiled or regional geologic map. The scale of the Landsat scene is usually different from that of either of the maps. Finally, the geologist hopes to compare all the data mentioned above to an intermediate-scale map showing gravity values. To accomplish this goal, the scientist may photocopy the maps to get them at approximately the same scale in order to superpose them on a light table or flip back and forth between images much in the way a cartoonist checks frames for animation. In the end, the geologist compares data from the various sources (topography, geology, satellite images, aerial photography, geophysics) to solve a specific problem. This task would be much less cumbersome and time-consuming if all the data sets could be put to the same map scale, datum, and geographic projection (georeferenced).

All of the comparisons and overlays for this example project can be accomplished easily and efficiently using a computer-based GIS. Such systems allow for the manipulation of data in a manner that is scale independent (e.g., analysis and presentation can be manipulated to any scale). In addition, GIS software includes utilities for placing information into a common projection (i.e., universal transverse mercator [UTM]) and datum. This not only allows the data sets to be superposed, but also gives them geographic content (e.g., a map or image location contains information with regard to its actual location in real-world coordinates). Figure 1 shows an example of various types of data from numerous sources that were combined through the use of the ARC/INFO and IMAGINE software.

In this paper we provide some insight into the development of geological databases from the perspective of a small start-up academic laboratory. We cover many types of geological and geophysical data, but much of the discussion emphasizes incorporation of existing geologic maps. For more general discussions of GIS, see the suggested readings at the end of this article.

ACQUIRING GEOLOGICAL AND GEOPHYSICAL INFORMATION

Many different types of data are of potential use for integrated geological and geophysical studies. These include information about the surface geology and subsurface geology, geophysical survey measurements (usually referenced to individual sample points such as seismic shot points), and a variety of other spatially referenced data such as topography, remote sensing data, and cultural features (Fig. 1). The data sets can be represented spatially in a variety of ways, including points, lines, and areas for so-called "vector" data sets, and grids, images, and scans for "raster" data sets. The actual information associated with each spatial entity includes an identifying code or address, and one or more attribute values. An example of a linear spatial feature with an attribute value might be a fault (line feature) classified as either normal, reverse, thrust, or strike-slip (attribute).

Some of these data sets can be acquired without charge or for nominal charges through government channels. Examples include individual point information such as gravity data and earthquake hypocenter locations, grids of aeromagnetic data, grids of digital elevation information (known as digital elevation models [DEMs], or digital terrain models [DTMs], and vector data sets including digitized cultural features such as the USGS digital line graph (DLGs) product or the U.S. Census Bureau's topologically integrated geographic encoding and referencing (TIGER) system files on roads, waterways, pipelines, and telephone poles. A partial listing of access information is given at the end of this article for some of these public data sets.

Raster data sets, such as DEMs, and point data sets, such as gravity measurements, are usually already available in a digital form that is relatively simple to import into a commercial GIS package. Most GIS software packages will import a variety of grid or image formats, and will also handle tab- or space-delimited ASCII text data tables, which can be generated or customized in a spreadsheet or text editor.

Other types of data, such as air photos, satellite images, and geologic maps, must be purchased from a government entity, purchased from a commercial contractor, or input into the system in-house. Of all sources to be put into a GIS database, geologic maps are one of the most difficult and expensive to incorporate. Generating digital products from existing paper geologic maps is usually very expensive through commercial contractors; generating them in-house, however, takes a large amount of personnel time. If a large volume of data must be digitized from complicated published maps such as geologic maps or soils maps, the project quickly becomes extremely labor intensive and expensive.

NATURE OF GEOLOGIC MAP DATA

To properly incorporate geological mapping information into a GIS database we must look at how geological mapping is performed. Geologic maps are constructed by on-site inspection of the rocks cropping out at the surface. Although global positioning system (GPS) technology is available today for defining field location, virtually all currently available geologic maps relied upon location by inspection and triangulation using topographic maps or standard aerial photographs. The features that are actually marked on the base are mostly the contact lines between the rock units, and the point and line symbols bearing structural information.

Even if a geologist produces a map that follows topography perfectly, the map still has distortions inherent in all field mapping. Both the aerial photographs and standard topographic maps have some distortion. Topographic maps are imperfect representations, because of projection-based distortions and various errors that accumulate during the mapping process. Aerial photographs are usually even worse, because of in-flight pitch and yaw, camera distortions, and elevation (parallax) effects. They are not maps, and unless they have been through an orthorectification process to remove flight and elevation effects, their distortion is uncontrolled.

Another aspect of geological mapping which can cause problems in database development is the fact that geological field mapping involves a great deal of real-time interpretation. Two geologic maps of a given area produced by different mappers are never exactly the same, owing to the individual interpretations that occur in the field (e.g., of location, nature of contacts, etc.). The problem is exacerbated when multiple maps of differing scales exist for an area.

All of these considerations currently affect the overall accuracy of surficial geological information available for input into GIS databases. Most field geologists consider the field mapping to be the most trustworthy or most basic of all the data sets in the database—it is the "ground truth" that can actually be observed in nature but it is also one of the most complex data sets and one of the most difficult to accurately reproduce on the computer.

TYPICAL PRECISION AND ACCURACY OF DATA TYPES

As discussed above, surface geological information usually has some inherent uncertainty because of the manner in which the data are initially recorded and transcribed. Even so, the geological information may still be some of the more spatially accurate information in the database because of the relatively precise scale at which it was acquired. Geologists typically map with a pencil or pen that produces a line width of approximately 0.3 mm. The resolution of the geological information on the original map or photographic base is thus about 0.3 mm or about 85 dpi (dots per inch). A geologist mapping at a scale of 1:24,000 using a 0.3 mm pencil produces line widths that represent approximately 7 m of ground distance, or dot areas representing approximately 50 m^2 on the ground. (For a view from the USGS, see Ulrich et al., 1992.) Thus the precision with which the geologist attempts to record the data is probably much better than the final spatial accuracy of the map would indicate. Both field precision and final map accuracy will probably improve drastically in the future, because of GPS technology.

Geophysical data sets such as gravity measurements are difficult to examine in terms of their precision and accuracy. The location and elevation are surveyed to within, and are usually recorded in the database to a precision of, a few meters in location and perhaps tenths of meters in elevation. The original spatial precision and accuracy probably were even finer than what is recorded in the database. However, the data points are usually very widely spaced (hundreds or thousands of meters apart), and the data are often interpolated to allow the information to be displayed with other, more closely sampled data sets. Thus, the accuracy of the interpolated values can be called into question during later analysis and display, if the scale of the project is too small.

Data such as earthquake hypocenter, waveform, and source mechanism information can cause even more scale-related problems. Whereas microearthquake activity may be very closely monitored by a tight local array, regional information can have errors in location of several kilometers or more. Of course, this type of information is not suitable for interpolation, and its utility is thus very scale dependent.

DATA ENTRY

Geological and geophysical data sets are usually a mixture of both vector and raster data. To preserve the information recorded on a geologic map (with a nominal feature size of 0.3 mm) requires approximately 10 million points per square meter of map (following the discussion of Tufte, 1983, p. 162). All of these points are data. Geologic contacts (lines) are data. But the points contained within the unit boundaries are also data (e.g., a particular rock type generated by the enclosing contacts; see below). In this case, a vector-based GIS will be more efficient and generate a more easily used database (see also Bedell, 1994). Geophysical data are also easily and efficiently entered as point data. Image data, such as air photos, are recorded in raster layers.

Geological data are typically digitized into the computer system either from paper maps on a digitizing tablet (pulling

Databases *continued on p. 4*

TABLE 1. ATTRIBUTE FIELDS AND VALUES FOR GEOLOGIC CONTACTS

Contact type	Exposure type	Subtype	Additional characteristics	Significance	Fault slip	Notes
Fault	x	x	x	x	x	x
Intrusive	x	x	x			x
Depositional	x	x	x			x
Isograd	x	x		x		x
Shear Zone	x	x	x	x		x
Map Edge		x				x
	Known	Normal	Ductile	Internal	No. m	
	Approximate	Reverse	Brittle	Unit boundary		
	Approximate (?)	Thrust	Sharp			
	Inferred	Right-lateral	Gradational			
	Inferred (?)	Left-lateral	Chilled			
		Conformable	Unknown			
		Nonconformable				
		Unconformable				
		Alluvial				
		Scratch				
		Study area				
		Unknown				

Note: x indicates that an entry can be made for that attribute field. For example, a fault could be classified as contact type = fault, exposure type = known, subtype = normal, additional characteristic = unknown, significance = internal. Alternatively, a map edge would only contain the information: contact type = map edge, subtype = study area.

Databases *continued from p. 3*

data) or by using a mouse to trace lines or locate points from a scan that is displayed on a computer screen (heads-up digitizing). Both methods produce acceptable results, but our greatest success and ease has been with heads-up digitizing. Heads-up digitizing relies on registering a scan of the geologic map. As noted above, topographic features (peaks, stream intersection, etc.) are typically used for registration purposes because these features are those the geologist most likely used for reference when making the map. Most geologic maps can be scanned at a resolution of 0.17 mm (about 150 dpi). This preserves the feature size and data density of the map. Higher resolutions can be used if needed. We often scan at 200 to 400 dpi on maps with high information densities.

Most optical scanning software has built-in contrast and brightness controls. These are useful for color balancing geologic maps. It is also possible to use these controls to enhance greatly the quality of black and white scans. For example, many maps printed with geologic features as black contacts on a grayed topographic background can be scanned so that the topography is faded out while the geology is retained (of course, some topographic reference points must be identified and marked for registration). This makes heads-up digitizing much easier because the topographic line noise is removed. Similar procedures are possible for color scans of existing geologic maps.

Vector features can be extracted from scanned maps via the heads-up digitizing technique discussed above, but it seems logical to use the computer for digitizing as much information as possible. Autotracing algorithms are becoming more common in commercial packages on all systems (for example, Adobe Streamline™ and utilities in ARC/INFO). Some of these can be used in either a fully automatic batch mode or some form of interactive point-to-point mode. Our experience with these programs is that they still require enough correction and touch-up work that heads-up digitizing is faster. Once it has been digitized by autotracing, the vector information still must have attributes assigned to individual elements.

ASSIGNING ATTRIBUTES TO GEOLOGIC DATA

A very powerful feature inherent in vector-based GIS systems is the capacity to assign complex attributes for geologic information. For example, different line types are used for geologic contacts that are well exposed (solid lines) vs. those that are only approximately located (dashed lines) or inferred or concealed (dotted lines). This sort of information can be associated with any geologic contact or feature. The assignment of the geologic information is the key element to using GIS packages with geologic and geophysical data; typically no actual modification to the software is necessary.

A simple statement that preserves the fundamental idea of geologic maps is that "rock bodies are defined by their contacts." This is our basic working model for constructing the spatial relation, or topology, of geologic units. The first step in making a geologic map is digitizing the contacts. Once the contacts are entered into a "coverage" or data layer, the contact lines are joined to form polygons that define the rock units. This is the same as making a geologic map that can be colored without error; the contacts and map edges completely enclose the rock units. The rock-unit polygons are typically placed in a separate coverage, which is subsequently assigned attributes (see below). An important aspect of this is that the contact coverage is still retained: it still contains all of the information about the separate contacts, whereas the rock-unit coverage contains only information about rock types.

Most of the attributes we assign to geologic contacts (Table 1) fit normal geologic usage, except for entries on a fault. Faults are unusual geologic contacts in that they can separate different units or run through the same unit (the same is true for shear zones). For this reason, it is important to identify whether the fault represents a unit boundary or is internal to the rock unit. This, of course, can be deduced once all of the contact data are entered and the topology is constructed. Omitting internal faults simplifies the rock-unit coverage (Table 2) by decreasing substantially the number of separate rock-unit polygons that are constructed and need further classification.

Many structural data are associated with specific points. Items such as strike and dip of bedding or foliation are point features as represented on a geologic map. We treat here other orientation data assigned to faults and folds as point data as well. Specifically, the symbols for the dip and strike of a fault or the striations on a fault are usually represented on a geologic map as a set of arrows emanating from the fault. These data are best recorded as a point containing the orientation attributes. The point data (Table 3) can be subsequently tied or related to a specific contact or rock body. This extends to such features as the position of bar and balls marking normal faults. It is best to preserve positions of marks on faults and other sorts of contacts. In general, when working with published maps, it is difficult to know what the geologist meant by the position of these features, so it is best to assume that their placement is important. Of course, thrust barbs and other items that ornament the mapping of a fault do not have any real spatial importance in most cases, so they do not have to be entered separately. However, if a fault changes from low to high angle along strike or changes from a strike-slip fault (arrows) to a normal fault (ball and bar), then the attribution and symbols should change accordingly.

Some structural data are associated with other line features. Fold axes and lineaments fall into this category. These data are recorded as lines with attributes as to their structural character. Symbols on the lines, such as fold type or plunge information are entered as point data (see above) and can be tied to the structural feature.

Dikes are perhaps the most difficult geologic feature to enter, because many dikes are narrow rock bodies, and thus they are commonly shown as lines on geologic maps. Therefore, it seems appropriate to enter dikes as line features even though they are rock bodies. Wide dikes (those much wider than the map feature size) are treated as rock bodies. Developing a line coverage for dikes separate from the contact line coverage allows us to carry the necessary rock-unit information with the dikes.

In the example here of a geologic map that has been digitized and attributed (Fig. 2), note that the features associated with each geologic element are explicit and easy to understand. This makes the map accessible to both casual and in-depth users (see below).

BASIC QUALITY ASSURANCE AND QUALITY CONTROL

A basic aspect of any data entry is quality assurance and quality control, to make sure that the data are properly entered and attributed. This is done typically by plotting the data according to data type (e.g., a plot of faults alone) and then comparing the attributes associated with that data type with the original source map. In this way, the attributions can be checked for the proper classification of the contact, rock unit, or point feature as well as digitizing accuracy. We have found that a person other than the one who did the digitizing or attribution should do the checking in order to minimize errors. This process is very tedious but necessary to maintain the integrity of the data set.

The attribution of geologic data is usually unambiguous for well-prepared geologic maps. We have found, however, that even published maps sometimes have errors (open contacts or missing unit labels). In these cases, the error is noted, and open contacts are extended to close the rock unit. Missing unit labels can sometimes be easily interpreted—e.g., for laterally continuous sedimentary successions in areas of simple structure. Digitizing errors include digitized contacts or data points that do not overlap the

Databases *continued on p. 6*

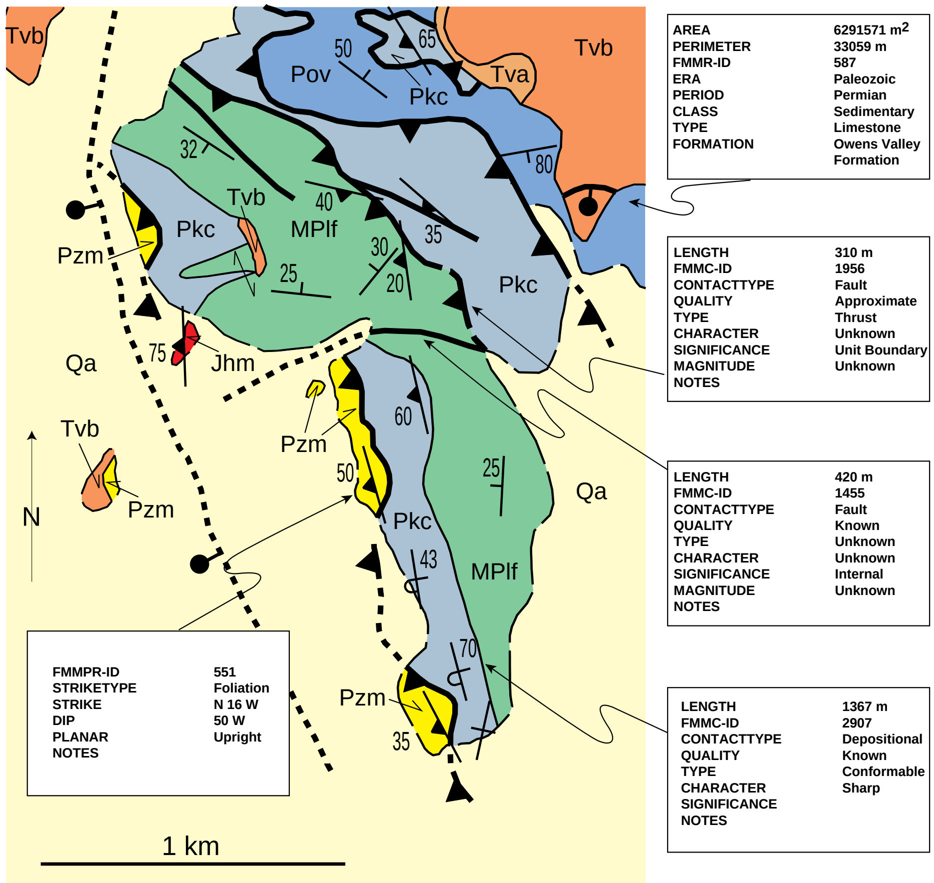

Figure 2. Part of the geological map of the northern Slate Range, California, from Moore (1976). The figure shows attributes given to various lines, points, and rock units. Rock units: Pzm, tectonite marble from Paleozoic rocks; MPlf, Lee Flat Limestone; Pkc, Keeler Canyon Formation; Pov, Owens Valley Formation; Jhm, Hunter Mountain quartz monzonite; Tva, andesite; Tvb, basalt; Qa, alluvium.

TABLE 2. ATTRIBUTE FIELDS AND VALUES FOR GEOLOGIC ROCK UNITS

Type of information about rock units	Geologic age (Era, period, stage)	Absolute age (if available)	Rock class	Rock type	Formation name	Notes
Age	x	x				x
Rock type			x	x		x
Formal name					x	x
		X ± Y Ma	Sedimentary Igneous Metamorphic	Basalt Andesite		

Note: x indicates that an entry can be made for that attribute field. See Table 1 for examples of how fields are attributed. In addition, the Notes field can be used for reference to any sets of external data (e.g., chemical analyses, or isochron information) for a rock unit. Many additional entries are appropriate for rock type.

Databases *continued from p. 5*

same feature on the scanned image. For contacts, we strive for 100% overlap, but in practice we consider 95% overlap acceptable for areas with tortuous or complex data. All point data, however, are edited to ensure 100% overlap. This is judged qualitatively by those who digitize and check the map data.

ANALYSIS VS. DIGITAL MAPPING

The reason that so much emphasis is placed on proper attribution of surficial geological data is that each symbol on the map represents an important data point to the original field mapper. Most of the individual symbols were recorded because they were in critical locations and communicated a specific piece of information about the geological history of the area.

Some commercial GIS digital products do not assign attributes to the point and line features found on geological maps. They sometimes simply digitize the shape of the symbols as a series of vectors. This may be sufficient for the sole purpose of reproducing a paper copy on demand. In this case, some commercial drawing programs, such as Canvas™ from Deneba Software and Adobe Illustrator™, work very well and are easy to use. However, if the reason for digitizing the map is to integrate field data for later analysis, the approach of just digitizing a shape is not adequate.

This is an example of the difference in basic philosophy between a digital cartographic system used for geological applications and a true GIS applied to geological problems. The digital cartographic system may be capable of producing very spectacular hard-copy products on demand, with some analysis capabilities (for example, the SuperCard system discussed by Condit [1995] for data presentation), but the GIS allows the geologist to work with the data, compile and analyze it, and to model it within the system. In addition, data sets from different sources and of variable type can be easily integrated for analysis and modeling.

This flexibility is also why we prefer to take the approach of not only assigning attributes to each symbol on a geological map, but also retaining all the information associated with each gravity data point, each earthquake hypocenter location, and each geochemical measurement input into a database. After all, the GIS should facilitate data manipulation. Most GIS software has fairly extensive tools to clean, smooth, or rasterize data sets once they are in the system, in addition to the extensive analysis tools. Simplified maps or plots to perform a specific task can always be derived from the complete data sets.

In addition, we have chosen to make fairly extensive and explicit tables of the attributes (see Fig. 2). Another approach is to make short alpha-numeric codes for contacts and rock units that are translated through a look-up table (similar to DLG format; see Wright and Stewart [1990] and Ulrich et al. [1992]). This is more efficient for storage and display purposes. However, given current advances in both computer and storage technology (ever-increasing processor speed and ever-decreasing storage prices) we feel that the space and time penalties of explicit tables of attribute values are trivial compared to the enhanced ease of use and readability. In addition, collections of explicit values in a table make query functions easy for casual users (using readily available products such as ARCVIEW™ by Environmental Systems Research Institute, Inc.). Complex coding schemes make it somewhat more difficult to examine data sets directly.

DATA SOURCES CURRENTLY ON THE INTERNET

Digital Elevation Model Information (DEM)
United States at 1:250,000—data points at 3 arc-second spacing
World Wide Web—
http://edcwww.cr.usgs.gov
(EROS Data Center home page)
Anonymous FTP—edcftp.cr.usgs.gov

Digital Line Graph Information (DLG)
United States at 1:2,000,000 and 1:100,000
World Wide Web—
http://edcwww.cr.usgs.gov (EROS Data Center home page) or more specifically

Databases *continued on p. 7*

TABLE 3. ATTRIBUTE FIELDS AND VALUES FOR GEOLOGIC POINT DATA

Type of geologic point data	Orientation of planar feature	Planar feature characteristics	Orientation of linear features	Sense of motion	Type of linear feature	Type of fold	Notes
Bedding	x	x					x
Intrusive contact	x	x					x
Depositional contact	x	x					x
Joint	x			x			x
Flow layering	x	x					x
Foliation	x	x		x			x
Shear zone	x	x	x	x	x		x
Fault contact	x	x	x	x			x
Foliation and lineation	x	x	x	x	x		x
Lineation			x		x		x
Axial surface (mesoscopic)	x	x				x	x
Fold axis (mesoscopic)			x			x	x
Map–scale fold type		x	x			x	x
Map–scale fold plunge			x			x	x
Bar and ball			x				
	Strike and dip	Upright Overturned Vertical Unknown	Trend and plunge	Up-dip Down-dip Right-lateral Left-lateral None Unknown	Intersection Depositional Flow, igneous Stretching Mineral Crenulation Slickenside Mullion Unknown	Antiform Synform Anticline Syncline Antiformal syncline Synformal anticline S-fold Z-fold Monocline Other	

Note: x indicates that an entry can be made for that attribute field. See Table 1 for examples of how fields are attributed.

Retrospective Electronic Index to GSA Journals, Books, & Maps Now on the Web

Jim Clark, GSA Production and Marketing Manager

GSA's Retrospective Electronic Index is now on the World Wide Web. This new, electronically searchable reference tool presents more than 11,000 bibliographic references, including journal articles from *GSA Bulletin* (1972–1995), all *Geology* articles (1973–1995), and all science articles from *GSA Today* (1991–1995). In addition, references for all books and maps ever published by GSA are included through 1995.

To use this powerful new tool it, all you need is computer access to the World Wide Web and an inexpensive or free Web browser (e.g. Mosaic, Netscape, MS Explorer). Go to GSA's home page (http://www.geosociety.org), click on the Publications link, then link to the Retrospective Electronic Index. You'll get a searching screen, from which you can set your search criteria: titles, author names, GeoRef keywords … anything in the data set.

This new approach replaces and greatly expands on the printed indexes that traditionally appeared in issues of GSA's journals in the past. Ever-rising costs of composition, printing, and distribution forced us to reexamine the way we publish these indexes. We are convinced that electronic indexes offer an excellent solution to those problems. Not only do they eliminate the costs of a large amount of paper, ink, and postage, they let us provide you with a far greater base of data: 23 years currently, rather than the traditional one; plus we are able to add *all* GSA books, maps, and transects ever published. Now you can search these data electronically, and mark and copy resulting data entries to paste into your word processor. You can build study guides, research and reference lists, bibliographies, and other applications quickly.

The data set includes, for each journal article: the full title of the article; names of all authors; and from 3 to about 40 key words assigned by the American Geological Institute's GeoRef system, a valuable, topical searching aid. Also included are the volume and issue number, year and month of publication, and counts of references and illustrations. For books, maps, and transects, the data set includes titles, authors, page counts, ISBNs, and other helpful information.

The search engine lets you search on all words and/or phrases in the data set. It also offers a limited type of conceptual searching. The search results consist of a set of links to the bibliographic material, with confidence levels and additional links to related data. In testing, most searches took only a few seconds to complete.

Give it a try, and by all means send us your comments or suggestions. Address E-mail to pubs@geosociety.org. For the present, use of this database is free, although a modest charge may be attached to its use in the future, at least for those who are not members of GSA.

Databases *continued from p. 6*

http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html
(the US GeoData home page)
Anonymous FTP—edcftp.cr.usgs.gov

For USGS products in general
World Wide Web—http://www.usgs.gov/

Topologically Integrated Geographic Encoding and Referencing System (TIGER) files—U.S. Census Bureau
World Wide Web—
http://www.census.gov:70/

Thematic Mapper—Landsat Information
Internet—xglis.cr.usgs.gov

Public-domain geophysics (potential fields, marine seismology)
Contact the National Geophysical Data Center: World Wide Web—http://www.ngdc.noaa.gov. Most of the NGDC data sets are not on-line, but can be ordered on CD-ROM from NGDC, Boulder, Colorado

Earthquake seismology
World Wide Web
General—http://geophys.washington.edu/seismosurfing.html
Specific networks—
http://quake.geo.berkeley.edu,
http://scec.gps.caltech.edu
World coverage—Passcal active experiments—http://www.iris.washington.edu

SUGGESTED READING

There are several good texts on geographic information systems. We have found the following books to give useful approaches or background:

Aronoff, Stan, 1989, Geographic information systems: A management perspective: Ottawa, Ontario, WDL Publications.

Bonham-Carter, G. F., 1994, Geographic information systems for geoscientists: Modelling with GIS (Computer Methods in the Geosciences, Volume 13): Kidlington, UK, Pergamon, 398 p.

Environmental Systems Research Institute, Inc., 1994, Understanding GIS: The ARC/INFO™ method: Redlands, California, Environmental Systems Research Institute, Inc.

HARDWARE AND SOFTWARE REQUIREMENTS

As computers in general become less expensive and more powerful, GIS products at all levels become more useful. How functional a GIS software product is, however, still depends somewhat disproportionately on the hardware on which the system is installed. For example, current versions of the most popular GIS packages are much more functional on UNIX work stations than on PCs and Macintoshes. The price reflects this fact: the differential is approximately 800% between the products, not simply because of speed differences of the machines, but because there are functions that you cannot buy in a PC version of the software. A full PC-based GIS package (at academic rates) would cost several hundred to a thousand dollars for the first license and one or two hundred dollars for each additional seat or machine. The equivalent UNIX-based package would cost several thousand dollars; additional seats would cost over a thousand dollars each.

ACKNOWLEDGMENTS

This work was supported by a contract from the Geothermal Program Office, China Lake Naval Air Warfare Center. We thank Frank Monastero for discussions on the nature of GIS and geological and geophysical data; Brian Macy, Dietrich Kastens, and Jerry Whistler for help with hardware and software problems; and Tim Byrne, Steve Davis, Randy Van Schmus, Rich Whitmarsh, and Suzanne Kay for beneficial reviews of the manuscript.

REFERENCES CITED

Bedell, R. L., Jr., 1994, GIS for the geosciences (short course notes for Geological Society of America Annual Meeting, Seattle, Washington): Richard L. Bedell, Jr. (Homestake, 1375 Greg St., Suite 105, Sparks, NV 89431), 193 p.

Condit, C. D., 1995, DDM-SVF: A prototype dynamic digital map of the Springerville volcanic field, Arizona: GSA Today, v. 5, no. 4, p. 69, 87–88.

Fitzgibbon, T. T., Wentworth, C. M., and Showalter, P. K., 1991, Digital compilation of geologic maps and databases using ALACARTE-ARC/INFO: Geological Society of America Abstracts with Programs, v. 23, no. 2, p. 25.

Jacobson, R. B., 1993, Application of a digital geographic information system in compilation and analysis of surficial geologic maps: Geological Society of America Abstracts with Programs, v. 25, no. 3, p. 25.

Moore, S. C., 1976, Geology and thrust fault tectonics of parts of the Argus and Slate ranges, Inyo County, California [Ph.D. thesis]: Seattle, University of Washington, 128 p.

Tufte, E. R., 1983, The visual display of quantitative information: Cheshire, Connecticut, Graphics Press, 197 p.

Ulrich, G. E., Reynolds, M. W., and Taylor, R. B., 1992, Toward digital geologic map standards: A progress report, *in* Johnson, A. I., et al., eds., Geographic information systems (GIS) and mapping—Practices and standards: American Society for Testing and Materials, ASTM STP 1126, p. 18–29.

Wentworth, C. M., and Fitzgibbon, T. T., 1991, ALACARTE user manual, version 1.0: U.S. Geological Survey Open-File Report 91-0587-C, 267 p.

Wright, B. E., and Stewart, D. B., 1990, Digitization of a geologic map for the Quebec–Maine–Gulf of Maine Global Geoscience Transect: U.S. Geological Survey Circular 1041, 16 p. ■