Evolution of Geological Mapping Methodology at GSC – Ottawa

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Since 1990, the Geological Survey of Canada (GSC) has made rapid advances in the development and implementation of digital methodology for management, integration, interpretation, and visualization of multidisciplinary geoscience data to aid regional geological mapping and mineral exploration. Advances in digital methodology have been made in many disciplines, such as geophysics and geochemistry, but are perhaps most dramatic in the field of geological mapping where computer methods have not generally been adopted. There had been no systematic attempt to utilize digital methodology in a seamless way throughout a project. It was felt that major improvements in integration of the disciplines and the speed of distribution and publication of the data, could be achieved if the geoscience data were kept in digital form throughout the project, from the field through to publication. Anticipated benefits of utilization of digital methods were:

1. The project database would become a published digital archive at the end of the project.
2. Field data, collected digitally, could be more efficiently be used to produce published maps using digital cartography.
3. The database would be a convenient source for data for all project participants.
4. GIS-based spatial analysis techniques would be more accessible if the data were in digital format.

Digital advances have been made in three general areas, field geology, project data management and analysis, and digital cartography and publication (Figure 1). Geologists now routinely utilize notebook computers and custom software in the field for data storage and preliminary map production. In the office, 2-D GIS technology is used to integrate, analyze, and visualize geophysical, geochemical, remote sensing, and other geoscience data while field data is used to refine interpretations. Subsurface interpretations and models of geophysical data from programs such as Lithoprobe are integrated with surface interpretations using 3-D visualization. 3-D software is also used to assist structural geologists in modelling and visualization of structural measurements and observations. Communication of project data and results is accelerated by routine use of digital cartography for production of map products, Internet communications for internal project communication, and Internet and CD-ROM as mechanisms for publication and distribution of archival project information. The success of digital methodology implemented by the GSC is dependent on the seamless integration of a number of independent initiatives, components, and tools.

FIELD OPERATIONS AND FIELDLOG

GSC geologists make extensive use of digital methodology during field mapping. Geologists are equipped with notebook computers and GSC-developed Fieldlog software (Brodaric and Fyon, 1989; Brodaric, 1992), digitizing tablets, and small printers to digitally record, display, and output daily field observations. At the outcrop, observations are recorded on airphotos and maps, in standard field notebooks, on preset forms, or in hand-held computers. Data are compiled at the field camp using a notebook computer and Fieldlog software, rather than using traditional manual drafting. Fieldlog software utilizes a relational database, especially tailored for geological data and spatial operations, and provides linkages to CAD or GIS software for visualizing and graphically adding or deleting field data. The database structure and contents are defined by the geologist and are modifiable at any time to accommodate the changing needs of field operations.

Digital methodology allows project-driven database and map construction to proceed in the field, resulting in a digital representation of the field data that is accessible during the course of the fieldwork. Upon completion of fieldwork, data can be easily edited and incorporated into other GIS, analysis and visualization software. Since the geology database is constructed at the source in the field, and intimately utilized during field mapping, it is current and immediately available for integration into larger GIS databases, without requiring duplicate data entry or error-prone transcription.

Fieldlog was initially developed at the Ontario Geological Survey and later modified and used extensively at the GSC and other federal and provincial agencies, universities, field schools and mineral exploration companies. In the last year the Regional Geology Subdivision of the GSC has modified Fieldlog (Brodaric, pers. comm., 1997). The latest version (3.0) still offers a flexible field data model, but constrains data to user-defined glossaries of geological terms throughout the data entry process.

In “Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration” *edited by* A.G. Gubins, 1997, p. 169–174

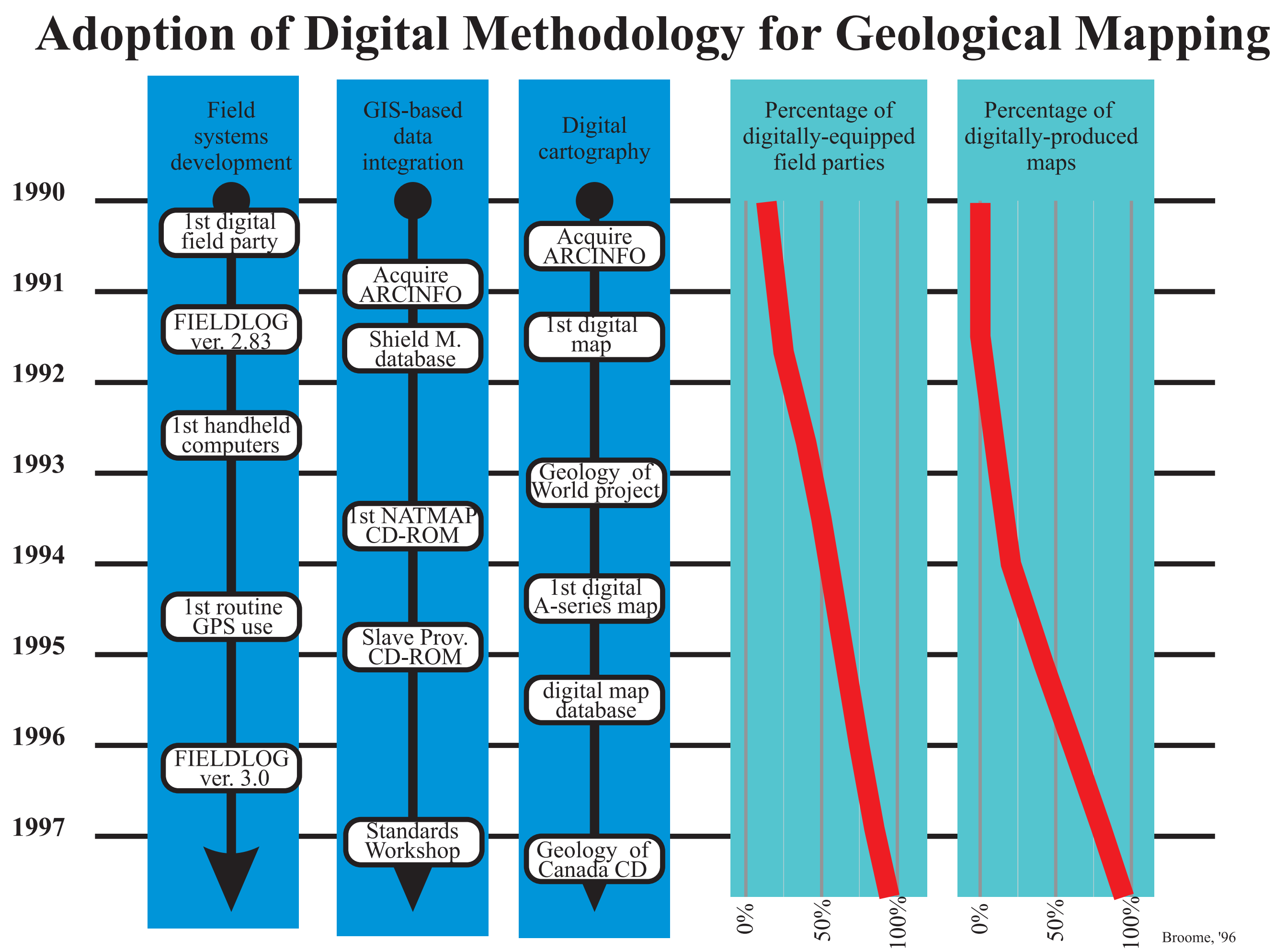

Figure 1: *Since 1990, evolution of digital methodology in three areas has resulted in an method to maintain data in digital form from the field through to publication.*

PROJECT DATA MANAGEMENT

The digital geoscience knowledge base, which includes a geo-referenced database together with models and interpretations, is the core of the digital initiative. The database contains all data relevant to the project goals, registered to a common projection and organized to allow combination, visualization, and analysis of data. A number of different types of geoscience data files and databases are in common use, with each type appropriate for particular applications. Listed in order of increasing organization of data they are often referred to as *plot files, map databases, and integrated GIS databases* (Figure 2). Although different nomenclature may be used in different organizations, most digital representations of geoscience data fall into one of these three categories.

Plot files, such as Postscript files, are used to produce a hard copy of a map on a particular type of output device. Plot files cannot be edited easily to incorporate new information, correct errors or modify scale or presentation. Map databases are designed to meet cartographic needs for a data storage model for production and revision of hard copy products. Data are more organized than in plot files, and individual map components (including graphic elements such as polygons, lines, and points) and attributes (such as colours, labels, and text) can be isolated and edited. Entire maps can be re-scaled, and application software, usually a GIS, can be used to create plot files for output on a wide range of output devices. Although map databases meet the needs of cartographers, they are somewhat scale-dependent and therefore not ideal for archiving project data. For example, in many instances available field data and observations are omitted on maps, due to the space and format limitations of hard copy products at specific scales. For optimum management of project data, scale-independent GIS databases are required. This type of database, although similar to a map database in some ways, is not linked to a particular hard copy product. Data sets, or layers, are stored independent of the scale and boundaries of map sheets, and attention is given to organizing the data in a way that preserves linkages between data and attributes facilitating querying and application of spatial-analysis techniques to multiple data sets. GIS databases can act as comprehensive archives of project data and may also contain the information found in map databases.

GSC project databases are designed as scale-independent GIS databases. In cases where geologists' field observations and measurements are available in digital form, these data can also be included. Although not all geologists are comfortable publishing their raw data and observations, this approach allows detailed field data to be archived along with the interpretive maps.

Before the project database is populated, a number of fundamental parameters must be specified including the base maps to be used, the projection, datum, and the data model. For major geoscience projects, a specified database manager acquires the core data sets for the study area, such as base maps and potential field data and accepts additional data from project participants as they are collected. In order for the digital approach to be successful, data must be both accessible to project participants and of high quality. The database manager is responsible for the management of all data in the database and for the generation and delivery of custom data sets and map products to project participants in appropriate formats. Project participants are encouraged to enlist the database manager to assist in application of GIS-based spatial analysis and visualization tools to the solution of geological problems.

STANDARDS

Project data management is most effective if mutually acceptable standards for both data content and format are available and well documented, particularly in multi-agency projects. Standards facilitate interchange and combination of data for analysis and visualization. Consensus is usually easier to achieve on format standards which deal primarily with the file formats, structure, and media used to interchange data. A flexible approach, in which the database manager accepts data in a range of formats from participants and performs, or assists in, reformatting of data for inclusion in the database, can be taken to simplify and encourage participation in the digital initiative. Raster data sets, such as geophysical imagery, are generally interchanged using BIL format files, vector and polygonal data using DXF or E00 format, and point data using DXF, formatted ASCII, or DBF formats.

Establishment of mutually acceptable data content standards is much more complex. In many geoscientific disciplines, such as geophysics, scientists have developed and adopted standards for the classification and organization of their data. As a result of these standards, geophysical data can be exchanged, combined, compared and interpreted across map and agency boundaries. Implementing standards for classification of geological observations is more problematic. The nomenclature and symbology for geological observations, features, and legends are highly variable between agencies and individual geologists.

ANALYSIS AND VISUALIZATION

One of the anticipated benefits of building a digital geoscience database is to facilitate application of computer-based interpretation methods. Two types of interpretation support are typically provided by the database manager: data visualization, and application of GIS spatial-analysis. Given the multidisciplinary nature of many projects, interaction between the disciplines is enhanced by the ability to easily produce customized integrated map and image products.

Composite images have proven particularly useful for visualizing the correlations between different data sets. Using an IHS transform (Harris and Murray, 1990), polygonal geological unit maps can be combined with other data sets such as shaded-relief aeromagnetic images and remotely sensed data. In the combined aeromagnetic/geology image, both the aeromagnetic textures and geological unit colours and contacts can be seen facilitating comparison. Line work and symbology can then be overlain to add an additional dimension to the integrated product.

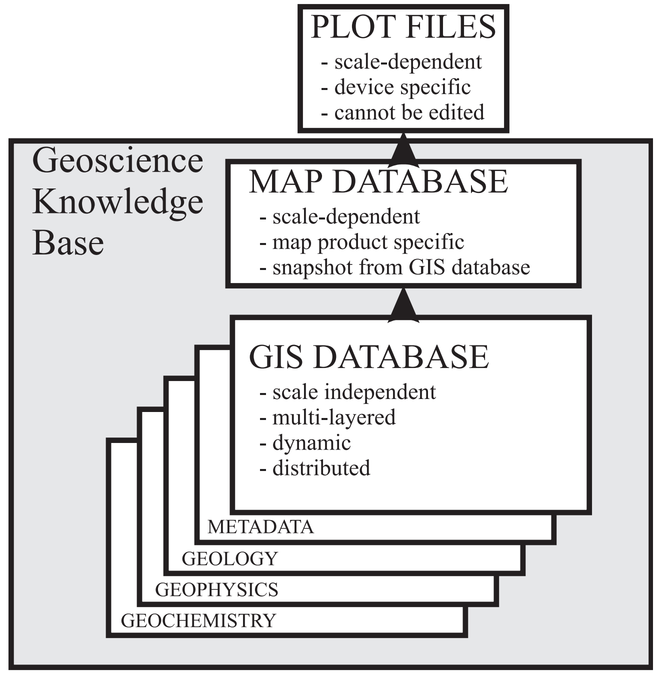

Figure 2: *Geoscience data is commonly stored in different degrees of organization for different purposes. In order of increasing organization*

In a NATMAP Shield Margin Project area, Lithoprobe seismic reflection data were collected along transects crossing the study area (Lucas *et al.*, 1993; White *et al.*, 1994). Since interpretation of seismic data typically involves careful extrapolation of subsurface reflectors to the surface and correlation with surface mapping, integration of the Shield Margin project data with the Lithoprobe seismic imagery promised to advance both projects. To compare the two interpretations, data were first registered to a common projection and then visualized in three dimensions. Most conventional GIS software, such as ArcInfo, are designed primarily for 2-D applications and are not able to manage or visualize true 3-D data. Analysis and visualization software capable of handling 3-D raster and vector data have been developed primarily for the oil and gas exploration community but have been priced beyond the means of most potential users. Fortunately new, less expensive software products are appearing with the required capabilities. One of these packages, IBM Data Explorer, was used to create perspective views (Figure 3) combining the seismic interpretations with surface geological mapping (Lucas *et al.*, 1993; Lewry *et al.*, 1994). These visualizations assisted in helping to create 3-D crustal geology models, interpret the geology off transect lines, and communicate interpretations to non-experts.

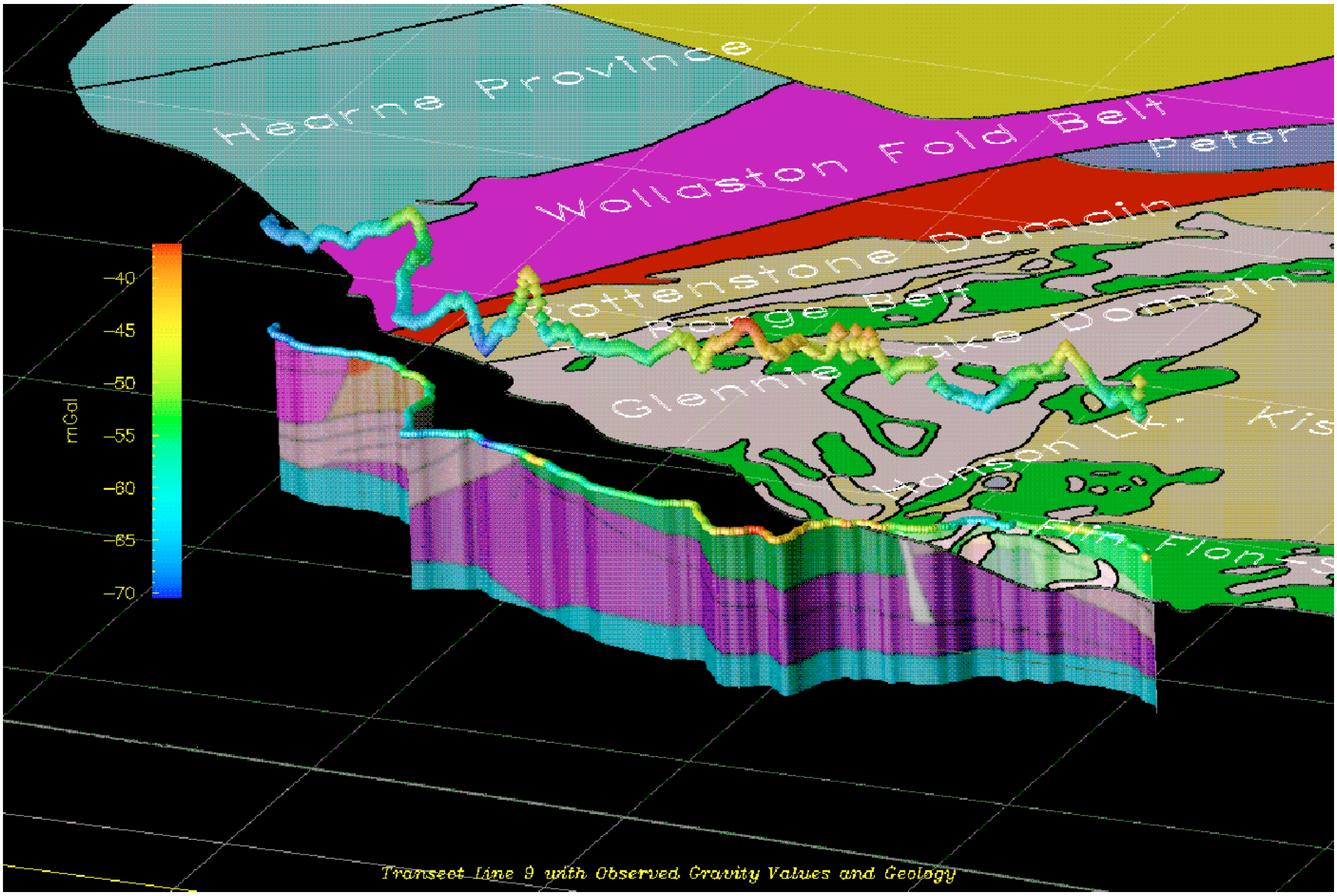

Figure 3: *Through 3-D visualization, surface mapping can be more easily compared to subsurface interpretations of geophysical data. In this example, surface mapping is displayed together with a geological interpretation of seismic reflection data collected as part of the Lithoprobe Trans-Hudson Orogen Transect.*

DIGITAL CARTOGRAPHY

Digital cartographic methods speed the production of both working and publication maps, particularly when data are provided to the cartographer by the geoscientists in clean digital format. Related benefits are the ability to use maps-on-demand printing of publication maps and the ease of map revision using digital methods. Maps-on-demand printing is much more efficient for producing small volume publications compared to traditional offset printing, which is only efficient when large quantities are required. The benefits of digital cartography have been discussed extensively elsewhere (Broome *et al.*, 1994).

DATA DISTRIBUTION

The success of projects is often measured by the number, quality, and timeliness of products produced. The NATMAP Projects have been leaders in the development of innovative integrated digital products. In 1993, a preliminary compilation of selected digital data was released on a CD-ROM for parts of the study area (Broome *et al.*, 1993). This prototype digital product included: bedrock and surficial geological maps and data, geophysical, remote sensing, and geochronological data together with base map data. These data were provided in formats suitable for both expert and neophyte users. For non-expert users, data were formatted to be compatible with ArcView, Version 1, a simple data visualization tool. All data were also provided in standard interchange formats such as E00 and DXF formats for more sophisticated users. At the end of projects, the contents of the project databases become an archive of all project data and can be published in CD-ROM format.

Effective communication is essential to successful interaction between participants, particularly in projects with many participating disciplines and agencies. A centralized project database can only be effective if the database manager can quickly and accurately communicate and exchange data with participants. The Internet has become an important and widely used tool for geoscientists. With project participants distributed throughout Canada, the Internet was the most efficient and inexpensive communication method for the GSC. Initially not all project participants had Internet access but now the majority of geoscientists or at least someone in their agency is on-line. Initially, simple E-mail and FTP tools were used by participants to transfer mail and data. Recently, the value of the World Wide Web (WWW) for communicating graphical and image data between participants has become apparent. Limited access web sites, or Intranet, has proven to be an excellent tool for communicating information within a geoscience project group.

THE FUTURE

Demand for digital geoscience data has increased exponentially. NATMAP and other GSC and provincial/territorial survey geoscience data are currently being released in scale-independent GIS-database format, such as the preliminary and archival Shield Margin CD-ROM products, or as map database files. While CD-ROMs are currently the most widely accepted and effective method for inexpensive distribution of large volumes of data, the next step in the evolution of digital data distribution will likely be on-line servers for data, which allow the user to interactively select and download data from distributed data servers for areas of interest. This method promises to be a faster, less expensive method of distributing data.

Geological mapping and mineral exploration involve management, visualization, and analysis of both 2-D and 3-D data. In the process of merging and visualizing the Lithoprobe and NATMAP data for the Shield Margin Project it rapidly became apparent that conventional 2-D GIS software was inadequate for this task (Desnoyer, pers. comm., 1996). Some productive visualization work has been done by exporting data from the project GIS database to a 3-D visualization package but clearly there is a need for true 3-D GIS software for management of project data. Much software development is being done in this area, and hopefully affordable 3-D GIS software will soon be available that offers the full functionality available with current 2-D GIS software. The availability of extensions to popular Internet browsers which provide 3-D visualization capability, such as VRML, will also open the possibility of communicating dynamic 3-D visualizations of interpretations through the Internet.

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