

Review of digital geological mapping techniques

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Abstract: The computer-assisted geological mapping becomes practical with the advancement in the computer technology. Field observation data can be recorded digitally and systematically using digital field data acquisition system. The incorporation of GPS technology to the system can help to speed up the field mapping in open areas. The digitally recorded field observation data can be used directly for the geological interpretation in the GIS environment. Geological interpretation can be performed more accurately and efficiently in GIS through effective use of spatial datasets from various disciplines, and the result can be used readily in the compilation of the geological map.

Abstraks: Pemetaan geologi berpanduan komputer dapat dilaksanakan dengan kemajuan dalam teknologi komputer. Data peninjauan kerja lapangan dapat direkod secara digital dan sistematik dengan menggunakan sistem pengambilan data digital. Pergabungan teknologi GPS dalam sistem itu boleh mempercepatkan pemetaan kerja lapangan di tempat yang luas. Data peninjauan itu dapat digunakan secara langsung untuk pentafsiran geologi dalam GIS. Pentafsiran geologi ini boleh dilaksanakan dengan lebih tepat and cekap melalui penggunaan data spatial yang terdapat dari berbagai bidang. Hasil pentafsiran itu boleh digunakan dengan mudah dalam penyusunan peta geologi.

INTRODUCTION

Geological map is of great importance to the mining and petroleum industry. Traditionally, the field observations are recorded on the field map and notebooks. These data are then used for the geological interpretation and compilation of geological map, which is manually carried in the office.

With the advancement in computer technology, suitable hardware and software become available for the computerisation of various geological mapping processes. Mobile computing hardware and software are now available, which enable the field observation data to be recorded digitally. Powerful desktop computers also become available to manage, analyse and visualise geo-spatial datasets from various discipline using the Geographic Information Systems (GIS), which allows geological interpretation to be carried more efficiently. Therefore, the geological mapping project can now be managed more efficiently with the help of computer technology.

This paper will discuss the review on the various aspects of computer-assisted geological mapping.

COMPUTER-ASSISTED GEOLOGICAL MAPPING TECHNIQUES

Geological mapping is traditionally carried out as a multi-stage manual field data collection, manual drafting and compilation processes.

The improvement in computer technology allows the computerisation for most of the geological mapping

processes as highlighted in Figure 1. Issues related to the computerisation of these processes, such as data sources, digital field data acquisition, digital conversion of printed maps, digital image processing, and geological interpretation and compilation in GIS environment will be discussed in the following sections.

Data sources

The sources of data that are required for the geological interpretation and compilation of geological map can be categorised into field observation data, and existing spatial datasets (Fig. 1).

The field observation data mainly consists of the observation point locations, field measurements, and detailed outcrop descriptions and sketches that are recorded

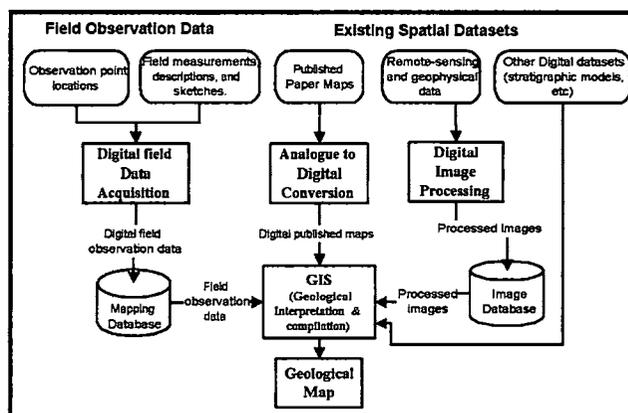


Figure 1. Computer-assisted geological mapping processes.

at each of the field observation points. Field map and field notebooks are traditionally used to record this field observation data.

The existing spatial datasets consists mainly of published maps (such as geological and topographic maps), remote sensing and geophysical images, and other digital spatial datasets (such as result of geological modelling). The published maps are mostly available in analogue format (printed-copies), whereas the remote-sensing and geophysical images, and geological models are normally available in digital format.

In order to use the above datasets in the computer-assisted geological mapping, they must be in digital format. To avoid duplication of effort in the data collection, Digital Field Data Acquisition Field system can be used to record the field observation data digitally in the field (Fig. 1). The existing published maps can be converted to digital format through the Analogue to Digital Conversion system. The remote-sensing and geophysical images can be registered to the same geographic coordinate system as the field observation data through Digital Image Processing techniques.

Digital field data acquisition

Traditionally, field map is used to record the location of rock exposures, rock and fossil samples, major contacts and structures observed in the field (Barnes, 1991). The detailed description and sketches of rock exposures, and field measurements are recorded in field notebooks.

With the advancement in the computer technology, mobile handheld PDAs and notebooks computers are becoming more powerful and affordable. Field data acquisition softwares with robust functionalities have also been developed, such as FieldLog (Brodaric, 1997), GeoMapper Universal (Brimhall and Vanegas, 2000, 2001), GSMCAD (Williams, 1997), GeoRover (GAF, 2003), Field Data Recorder (Rockware, 2003), and ESRI ArcPad (Bell, 2002).

Several organizations have started to use these digital field data acquisition systems for their geological mapping programmes. For instance, the Canadian Geological Survey has pioneered digital field data compilation using the Apple Newton PDA (Brodaric, 1997). US Geological Surveys (USGS) field geologists have followed and now have several years of experience using later generation PDAs such as Palm Pilots or Pocket PCs (Walsh *et al.*, 1999a, 1999b).

All the above field data acquisition systems allow systematic collection of the field observation data using the customised data entry forms. Systems like FieldLog, GSMCAD, GeoRover, Field Data Recorder, and ArcPad also have GPS interface for retrieval of sample/outcrop location data in Latitude/Longitude or UTM format. The incorporation of GPS technology (Lange and Gilbert, 1999) in these systems can speed up the field mapping, particularly in open areas.

Friendly user-interface has also been emphasized by some of the systems. For instance, GeoMapper Universal

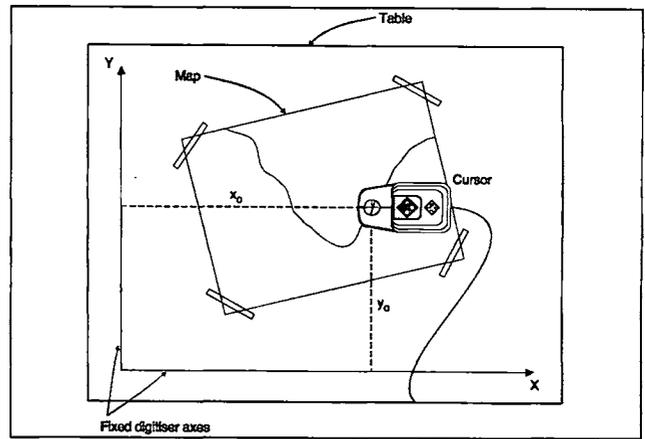


Figure 2. Digitising table setup. The geological boundaries on the map are digitised in vector mode according to the Cartesian coordinates of the table (after Graeme, 1996).

provides a visual user interface (VSI) for geologist to personalise the mapping legend for local geology on a project basis, and another VSI for geologist to learn the mapping system. This system implements the mapping tools using button icons, which are displayed in a general sequence guiding the selection of mapping tools as one proceeds to map in a desired fashion.

Some of the field data acquisition systems can also be customised to suit the user requirement. For instance, ESRI ArcPad 6.0 can be customised to allow digital recording of the field observation data (attribute) as well as spatial data (points, lines, and polygons) drawn over base map or orthophoto images.

On the whole, the field observation data recorded digital using these systems are managed more efficiently using the computer database than the traditional methods. Routine backup procedure can be implemented to prevent any loss of the valuable field observation data. Besides, the field observation data stored in the mapping database can be readily transferred to the GIS environment for the geological interpretation at a later stage.

Digital conversion of existing paper maps

A major proportion of the effort involved in setting up digital mapping system relates to acquisition of datasets in digital form, and to get all the acquired maps, images, and spatial datasets in correct spatial register (Graeme, 1996). Two methods can be used for converting the existing paper maps into digital format, i.e. manual digitising and vectorisation of scanned maps.

Manual digitising uses a digitising table that is equipped with a stylus or cursor for tracing and electronically recording the positions of points and lines shown on the map. This manual operation should always be carried out in a rectangular coordinate system that is defined by the digitising system (Dowman, 1999). The map to be digitised is mounted on the digitising table, taped securely to prevent movement, and traced with the cursor (Fig. 2). Control points are then defined on the map and used to determine

the transformation parameters for converting from table coordinate to projection coordinates of the input map (Graeme, 1996). The manual digitising can be carried out in point, line or stream mode. Individual locations (such as sample sites, well location) are recorded in point mode as single coordinate pairs. Line features such as faults, lineament, and geological contacts are recorded in line mode, or stream mode. After digitising, the result needs to be carefully checked and edited to ensure everything has been recorded correctly. If carried out systematically and carefully this method can produce accurate and complete vector data. However, this manual operation is tedious and time-consuming.

Optical scanners, either of the rotating drum (Fig. 3) or flatbed variety, have been used for cartographic data entry since mid-1960s (Carstensen and Campbell, 1991). The scanner can be used to obtain scanned image of existing paper map. The scanned image is then rectified to a geographic base with control points through coordinate conversion (Graeme, 1996). The vector features on this scanned map can then be extracted through the vectorisation process (Able Software Corp, 2003).

The vector data extracted from the published map using the above techniques can then be converted into spatial datasets using GIS software.

Digital image processing for remote-sensing image

Multispectral remote sensing data has shown tremendous potential for applications in various branches of geoscience (Gupta, 1991). Digital image processing techniques, such as image correction, image registration, and image enhancement are of particular importance to geological application of the remote-sensing data.

The various radiometric and geometric distortions in the remote-sensing data can be removed through the image correction technique.

Image registration is used to superimpose the remote-sensing image with other spatial datasets (such as field observation data, published maps, etc.) with geometric precision. This is necessary for the accurate geological interpretation using these datasets in the GIS environment. Prominent features, such as road intersections, and river bends or junctions on the remote-sensing image are identified as ground control points (GCP). GPS equipment is then used to obtain the geographic coordinates of these GCPs during the field mapping. By applying image registration, this remote-sensing image is transformed from the image coordinate to the geographic coordinate based on the coordinates at the GCPs.

Image enhancement is used to highlight the important features in the remote-sensing images to facilitate the geological interpretation by the geologist. For instance, edge enhancement is applied to remote-sensing image to produce a sharper image with more details such as fractures and joints systems. Spectral ratioing is used to produce a

remote-sensing image that is quite independent of illumination conditions. Some of the spectral ratios of Landsat TM data are useful for surface discrimination as listed in Table 1.

Software packages that can be used for the digital image processing include ER Mapper, and Interpid.

Geological interpretation and compilation in GIS environment

Traditionally, the compilation of geological map is carried out manually in the office after the field-mapping programme. The field observations recorded on the field map and notebooks, as well as any other published maps and remote-sensing images are used in the geological interpretation (Barnes, 1991; Spencer, 1993). Preparation of these datasets to the correct scale and format is necessary prior to the geological interpretation. The relevant maps and images may need to be enlarged or reduced to a common scale. Field mapping traverses and recorded field measurements (such as strike/dip etc.) are then manually plotted at the same scale as the other maps. All these maps and images, as well as the field measurement plots are then placed over each other correctly on a light table for geological interpretation. During the compilation of geological map, the geological contacts shown on the field maps are manually traced to a new Mylar sheet. Inferred faults/folds and inferred geological boundaries are then drawn on the Mylar sheet based on the interpretation using all the available datasets.

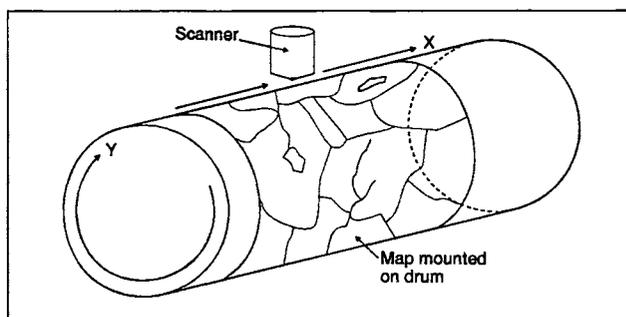


Figure 3. Rotating drum raster scanner. The scanning head moves in increments along the X direction, parallel to the long axis of the drum. The map moves in the Y direction with respect to the scanning head by drum rotation (after Graeme, 1996).

Table 1. Important TM ratios for surface compositional discrimination (after Drury and Hunt, 1989).

TM Ratio	Application
7/5	Argillic versus non-argillic
3/4	Rocks versus vegetation
5/1	Fe ³⁺ + Fe ²⁺ versus iron-free
5/4	Argillic versus Fe ²⁺
4/7	Argillic versus Fe ³⁺
4/2	Fe ²⁺ versus non-Fe ²⁺

With the advancement in the computer technology, the geological interpretation and compilation of geological map can be carried out more efficiently within the GIS environment (Baker, 1999; Krumm, *et al.*, 1997).

The field observation data stored in the mapping database can be used to generate various layers of field observation maps (such as strike/dip, lithofacies, fossils etc.) that overlie each other accurately in geographic coordinate (Fig. 4). All the detailed description, sketches and photographs recorded at each of the field observation points can also be accessed easily by selecting the spatial features shown on these map layers. Any updating made to the field observation data in the mapping database will automatically update the map layers and their associated data.

Any other relevant digital spatial datasets (such as remote-sensing and geophysical images, published maps, geological models, etc.) in the correct format can also be loaded as additional map layers in the GIS to assist the geologist in the geological interpretation. For instance, remote-sensing data from aerial or space platform can be used to delineate vertical to high angle faults or suspected fault (Gupta, 1991). Lithological information can also be deduced from a number of parameters observed on remote-sensing images, such as general geologic setting, landform, drainage, structural features, soil and vegetation, and spectral characters.

Spatial analysis functions of the GIS can be used to analyse the spatial relationship between the various field observation data (such as lithofacies, strike/dip measurement, etc.), and the existing spatial datasets. The result of these spatial analyses can be added as a new map layer in the GIS to facilitate the geological interpretation.

The geological interpretation based on multi-disciplinary data in the GIS environment has not been fully automated yet. However, the geological interpretation can be carried out by the geologists more accurately and efficiently under the GIS environment than the traditional method, through effective use of the digital spatial datasets from various disciplines. Each of the map layers displayed in the GIS can be turned on or off easily, so that the right combination of datasets can be used for the geological interpretation. The results of the geological interpretation are also managed efficiently as new interpretation map layers (such as geological formations, structure, etc.) in the GIS environment.

The GIS also help to accelerate the compilation and production of the geological map (Dohar and Everett, 2000). The interpretation map layers and other existing map layers (such as topographic map) can be used readily for the compilation of the geological map. The map layout and legend for the geological map can also be generated easily in GIS. Therefore, the geologists can compile the geological map entirely within the GIS environment, without the need of preparing draft drawings to be digitised or drafted by others in the traditional method.

Several commercial GIS software package are

available, which include ESRI ArcInfo/ArcView, MapInfo, and Manifold.

DISCUSSION

Generally, geological mapping processes can be improved through the use of computer technology. Several issues need to be considered for the successful implementation of the computer-assisted geological mapping. These include the acquisition of digital spatial datasets, and selection of suitable tools for the field data acquisition and geological interpretation.

The digital spatial datasets constitute one of the most important components for the geological interpretation in the GIS environment. The acquisition of these datasets also takes up most of the effort in computer-assisted geological mapping. Therefore, care must be taken to ensure that these digital datasets are captured correctly and accurately. Correct map projection and coordinate system must be used during the digital field data acquisition, and conversion of printed maps to digital format. Besides, metadata for these spatial datasets must be available for the geologist to select suitable spatial datasets for the geological interpretation.

The selection of hardware and software also plays an important role in the successful implementation of computer-assisted geological mapping. The field mapping conditions need to be considered during the selection of the hardware (handheld or notebook computer) for the digital field data acquisition. The selected hardware must be able to withstand these field conditions throughout the field-mapping period. The field data acquisition software chosen must be compatible with the selected hardware, user-friendly and robust, so that the field mapping process can be carried out smoothly. Similarly, the field data acquisition hardware

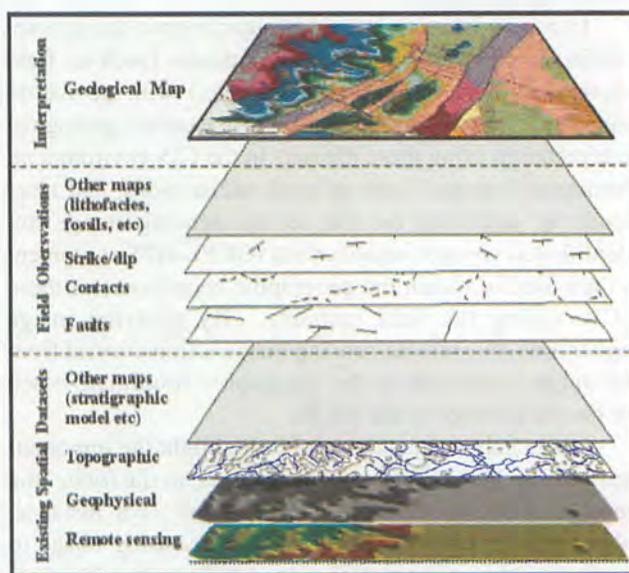


Figure 4. Illustration on using various map layers for the geological interpretation in GIS environments.

and software must also be compatible with the geological interpretation system (GIS) to ensure seamless transfer of field mapping data between the systems.

CONCLUSION

With the advancement in computer technology, suitable hardware and software become available for the computer-assisted geological mapping, which has several advantages over the traditional methods.

The field observation data can be collected more systematically using the customised data entry forms provided by the digital field data acquisition system. This digitally collected field observation data are managed more efficiently using the computer database than the traditional methods. Routine backup procedure can also be implemented to prevent any loss of the valuable field observation data. The incorporation of GPS technology to the system also helps to speed up the field mapping in open areas.

The digitally recorded field observation data can be used readily for the geological interpretation in the GIS environment, without the hassle of manually plotting the observation points and other field measurement as required by the traditional methods. Various map layers can be generated easily from the digital field observation data in the mapping database. Any other digital spatial datasets in the correct format can also be added to the GIS environment easily. Therefore, the geological interpretation can be carried out accurately and effectively in the GIS environment, through effective use of all the available digital spatial datasets from multi-disciplines.

The result of the geological interpretation can be used readily in the compilation of the geological map, which eliminates the redundancy of preparing draft drawings to be drafted by others in traditional method. Finally, any updating to the geological map can be carried out fairly easily. The geological map can also be published as printed copies using plotters, or as digital geological map stored in CD-ROM.

Several issues need to be considered for the successful implementation of the computer-assisted geological mapping, particularly on the acquisition of digital spatial datasets, and the hardware and software selection.

REFERENCES

- ABLE SOFTWARE CORP., 2003. *R2V: Advanced Raster to Vector Conversion Software for Automated Map Digitising, Being Used in More Than 60 Countries*. Able Software Corp. URL: <http://www.ablesw.com/r2v/r2v.html>
- BAKER, H.W., 1999. ArcView, a Geologic Mapping Tool. In: D.R. Soller, (Ed.), *Digital Mapping Techniques '99 - Workshop Proceedings: U.S. Geological Survey Open-file Report 99-386*. <http://pubs.usgs.gov/of/of99-386/baker.html>
- BARNES, J., 1991. *Basic Geological Mapping*. 2nd Edition. John Wiley & Sons, New York, 118p
- BELL, J.L.S., 2002. ESRI ArcPad 6.0. *Professional Survey Magazine*, July 2002.
- BRIMHALL, G.H. AND VANEGAS, A., 2000. Digital mapping of geology and ore deposits with GeoMapper. *Geol. Soc. Amer. Abstracts with Programs*, 32(7), A514.
- BRIMHALL, G.H. AND VANEGAS, A., 2001. GeoMapper Universal Digital Pen Mapping System for Geological, Mining, Exploration and Environmental Mapping with a Point and Click Legend Maker and Project-based File Manager. *Proceedings, 2001 Annual Conference of the International Association for Mathematical Geology Cancun, Mexico September 6-12, 2001*.
- BRODARIC, B., 1997. Field Data Capture and Manipulation Using GSC Field log v.3.0. In: Soller, D.R. (Ed.), *Proceedings of a Workshop on Digital Mapping Techniques: Methods for Geologic Map Data Capture, Management, and Publication U.S. Geological Survey, Open-file Report 97-269*, 77-81, <http://pubs.usgs.gov/openfile/of97-269/brodaric.html>.
- CARSTENSEN, L.W. AND CAMPBELL, J.B., 1991. Desktop scanning for cartographic digitisation and spatial analysis. *Photogrammetric Engineering & Remote Sensing*, 57(11), 1437-1446.
- DOHAR, V. AND EVERETT, D., 2000. Geological Map Production for Dummies. In: *Digital Mapping Techniques '00—Workshop Proceedings: U.S. Geological Survey Open-File Report 00-325*. <http://pubs.usgs.gov/of/of99-386/baker.html>
- DOWMAN, I.J., 1999. Encoding and validating data from maps and images. In: Longley, P.A. et al. (Eds.), *Geographical Information Systems—Principles and Technical Issues, Volume 1*. John Wiley & Sons, Inc. New York, 437-450.
- DRURY, S.A. AND HUNT, G.A., 1989. Geological uses of remotely-sensed reflected and emitted data of lateritized Archaean terrain in Western Australia. *International J. Remote Sensing*, 10(3), 475-497.
- GAF AG, 2003. GAFWare GeoRover. http://www.gaf.de/html/main/gafware_mapping_georover.html
- GRAEME, F.B., 1996. *Geographical Information System for Geoscientists – Modelling with GIS*. Pergamon, U.K., 398p.
- GUPTA, R.P., 1991. *Remote Sensing Geology*. Springer-Verlag, Berlin, 356p.
- KRUMM, R.J., ABERT, C.C., NELSON, D.O., AND HESTER, J.C., 1997. Review of Digital Mapping Techniques: The Illinois Experience. In: D.R. Soller, ed, *Digital Mapping Techniques '97—Workshop Proceedings: U.S. Geological Survey Open-file Report 97-269*. <http://pubs.usgs.gov/of/of97-269/krumm.html>
- LANGE, A.F. and Gilbert, C., 1999. Using GPS for GIS data capture. In: Longley, P.A. et al. (Eds.), *Geographical Information Systems – Principles and Technical Issues, Volume 1*. John Wiley & Sons, Inc. New York, 467-476.
- ROCKWARE, 2003. Field Data Recorder - A Pocket PC, MS Access database application for recording environmental, geologic and drillhole data in the field. [_http://www.rockware.com/catalog/pages/fieldrecorder.html](http://www.rockware.com/catalog/pages/fieldrecorder.html)
- SPENCER, E.W., 1993. *Geologic Maps. A Practical Guide To The Interpretation and preparation of Geologic Maps*. Macmillan Publishing Company, New York, 147p.
- WALSH, G.J., REDDY, J.E., AND ARMSTRONG, T.R., 1999. Geologic Mapping and Collection of Geologic Structure Data with a GPS Receiver and a Personal Digital Assistant PDA Computer. In: D.R. Soller (Ed), *Digital Mapping Techniques '99—Workshop Proceedings. U.S. Geological Survey Open-file Report 99-386*, 127-131. <http://pubs.usgs.gov/openfile/of99-386/walsh.html>.
- WALSH, G.L., REDDY, J.E., ARMSTRONG, T.R., BURTON, W.C., 1999.

Geologic mapping with a GPS Receiver and a Personal Digital Assistant Computer Streamlines Production of Geologic Maps. *Geological Society of America Annual Meeting. Abstracts with Program*, 31(7), A-192. <http://www.geosociety.org/>.

WILLIAMS, V., 1997. Using the GSMCAD Program with GPS for

Data Collection in the Field and as a Quick and Efficient Way of Creating Arc/Info Geologic Map Coverages. In: D.R. Soller, ed, *Digital Mapping Techniques '97*. U.S. Geological Survey Open-File Report 97-269 <http://pubs.usgs.gov/of/of97-269/williams.html>

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