Second National Forum on GIS in the Geosciences - Forum Proceedings

AGSO Record 1995/46

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Second National Forum on GIS in the Geosciences

29 - 31 March 1995

Australian National Library

Forum Proceedings

AGSO RECORD 1995/46

Australian Geological Survey Organisation

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: Hon. David Beddall, MP
Secretary: Greg Taylor

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Neil Williams

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FORUM DETAILS & ACKNOWLEDGEMENTS

This Second National Forum on GIS in the Geosciences follows the earlier GIS, Cartographic and Geoscience Data Standards Workshop of 18-20 March 1992 (BMR Record 1992/27).

OBJECTIVES

The objectives of this Forum were:

- To examine best practice in the application of GIS in government and industry, with an emphasis on geoscience-related applications, standards and allied technology;
- To encourage the flow of experience and ideas, and to help keep up with rapid change.

SPONSORS

The support of the following official sponsors is gratefully acknowledged:

- Australian Geological Survey Organisation
- Government Geologists Database Policy Advisory Committee
- Chief Geological Cartographers
- Silicon Graphics Pty Ltd
- ESRI (Aust.) Pty Ltd

GGDPAC

The Government Geoscience Database Policy Advisory Committee (GGDPAC), is a formal coordinating group for common geoscience data-related efforts and responsibilities in the public sector. It was set up by the Chief Government Geologists, who in turn report to the Australia & New Zealand Minerals and Energy Council (ANZMEC) - a peak States/Federal Ministerial Council. GGDPAC is recognised by the Australia New Zealand Land Information Council as representing public sector geoscience interests on national policy, standards and technical issues and is represented on relevant committees of Standards Australia.

PARALLEL MEETINGS

Chief Government Geologists annual meeting, AGSO	27-28 March 1995
GGDPAC annual meeting, AGSO	Mon 27 March 1995
Government Technology Conference & Exhibition, NATEX, ACT	28-30 March 1995
AMIRA P431 project: Geoscience Data Model; sponsors' meeting	Tues 28 March 1995
ArcView & MapInfoGIS workshops & Map Production workshop	Tues 28 March 1995
2nd National Forum on GIS in the Geosciences, National Library	29-31 March 1995

BEHIND THE SCENES

The assistance of many people within AGSO behind the scenes is gratefully acknowledged. In particular, those who helped with exhibition and poster displays, Forum location and social/dining planning. Dinner in the Old Parliament House Members' Dining Room was a great success, with wise words from Brian Lees. Jenni Wines and Margie Ward went beyond the call of duty in their smooth administrative management.

Special thanks also to Jenni for producing this Record and to session chairs, authors and speakers. Please **take note** that not all speakers provided papers or abstracts. For this reason, the actual program is included, as well as separate compilations of the available abstracts and the papers provided. Using the program as an index, you can then locate either an abstract or paper (or both) for a speaker.
David Berman, Forum Convenor & Editor

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Government Developments Chair David Berman

AGSO

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9:20 - 9:40	**Creating mineral province GIS packages - issues, problems, solutions, opportunities and visions** Lesley Wyborn, Oliver Raymond, Regional Geology & Minerals (RGM) Division, AGSO; and Robyn Gallagher, GISolutions
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Exhibitions, demonstrations, posters, free time

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Adrya Kovarch, Peter Flood and David Moore, GeoMapping Technologies Pty Ltd

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Chris Jenkins, Ocean Sciences Institute Geology & Geophysics, Uni. Sydney

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David Berman, AGSO

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Richard Hume and Don Miller, AUSDEC

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Richard Hume and Don Miller, AUSDEC

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R. & D. APPLICATIONS Chair John Creasey

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Robert Holloway, Racal Survey Aust. Ltd

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Bob Gozzard and Don Hunter, CRC-AMET, WA

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FORUM INTEGRATION & SYNTHESIS Chair David Berman

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3:30 - 4:00 Refreshments

2:00 - 6:00 Parallel visits to AGSO Cartography & Spatial Data Processing Centre

2:00 - 6:00 Exhibitions, demonstrations, posters

ABSTRACTS

1. GOVERNMENT DEVELOPMENTS

Australian Geological Survey Organisation

TOWARDS INTEGRATED SPATIAL INFORMATION SYSTEMS IN AGSO - AN OVERVIEW

David Berman, Director, Information Services Division, AGSO, CANBERRA

AGSO was in the Geo-referenced Information business long before it became fashionable as GIS. The evolution of a number of discipline and project-based systems is described; as is the process of organisational change as the internal needs for data management, integrity, standards, custodianship, exchange and access, as well as new client needs drive the organisation towards an integrated approach.

CREATING MINERAL PROVINCE GIS PACKAGES - ISSUES, PROBLEMS, SOLUTIONS, AND OPPORTUNITIES

Lesley Wyborn[1], Robyn Gallagher[2] and Ollie Raymond[1]

[1]Australian Geological Survey Organisation, CANBERRA; [2]GISolutions, CANBERRA

With continuing software developments in Geographic Information Systems (GIS), it is becoming increasingly obvious that the capacity of GIS to integrate and analyse data can now exceed limitations imposed by the quality of primary digital data that can be incorporated. In the geological community, the calibre of GIS packages developed, and the time taken to prepare them, is being limited by issues such as the varying quality of the digital data sets that are available (including maps). More often than not, data quality relates to the diverse ways in which these primary data sets are captured and then documented. Care taken in the initial stages of data capture, and the effort put into data validation and ensuring internal consistency between different themes can determine the quality of the final integrated GIS package, which in turn dictates how effective the package will be in metallogenic analysis. The major issues that constrain the creation of effective national geoscience GIS packages are the gross lack of uniform national data capture, data transfer and data storage standards. There is also the issue of the need for geological training that emphasises the importance of validated digital data sets. If some attention is given now to addressing these issues, then comprehensive national digital geoscientific data sets will be an achievable goal giving the geoscience community at large the opportunity to make valid contributions to national issues such as environment, agriculture, and human health.

PREDICTING RADON HAZARD IN AUSTRALIA USING ASSESS

Robyn Johnston[1] and Julie Bowyer[2]

1. Environmental Geoscience and Groundwater, AGSO
2. National Resources Information Centre, BRS

Exposure to elevated indoor radon levels is thought to cause up to 10% of lung cancers internationally. Radon levels are primarily determined by geological factors such as the distribution of uranium in soils and rocks, soil depth and permeability and groundwater movement. GIS techniques can be used to predict areas with high radon hazard potential. Existing geological, geochemical and geophysical data were combined using ASSESS, a risk assessment software package, to provide a preliminary assessment of areas with high radon potential at continental scale, and for a regional case study for the Collie region in Western Australia.

GIS DATABASE OF MURRAY BASIN HYDROGEOLOGY

Ross Brodie, Jenny Lane & Warren Overton, Environmental Geoscience and Groundwater Division, AGSO, CANBERRA

Salinisation of land and surface water is seriously degrading the natural environment and sustainability of agriculture in the Murray Basin. These problems are groundwater related, so a 1:250 000 scale hydrogeological mapping program was initiated between State water agencies and the Australian Geological Survey Organisation (AGSO). The 26 mapsheets were completed in 1994 and contain information on depth to water table, tops of regional aquifers, salinity, water levels and sustainable aquifer yield. AGSO is preparing a digital database from the mapping, using Arc/Info. Over 400 GIS coverages have been created from the Intergraph IGDS files used in map production. Themes from each mapsheet are appended to create seamless basin-wide datasets. To assist in the conversion process, AML-based tools were developed and integrated into a modified version of ArcTools. The interface also includes tools to help validate datasets and assist in compiling metadata. Compilation of the GIS product has greatly enhanced the utility of the hydrogeological information. Customised basin-wide maps of themes such as salinity hazard, potable and stock water supplies have since been generated. The introduction of GIS technology into this map series has dramatically changed how future mapping programs will be planned and implemented.

MAP PRODUCTION WORKSHOP OUTCOMES REPORT

Ian O'Donnell, Chief Cartographer, Information Services Division, AGSO, CANBERRA

A report from the Map Production Workshop on Techniques, Standards and Issues, held in conjunction with the GIS Forum, on Tuesday 27 March, 1995, at AGSO.

This workshop is targeted at practitioners involved in designing, producing and publishing high quality geoscientific map products. It aims to present a comprehensive update on strategies employed by the respective State/Territory Geological Surveys for digital map production, and identify those issues which are fundamental to optimising the processes.

SPATIAL INFORMATION SYSTEMS AND BASIN RESOURCES EVALUATION

Tom Loutit, Chief, Marine Petroleum and Sedimentary Resources Division, AGSO, CANBERRA

Spatial information systems are fundamental to the evaluation of the timing, distribution and character of resources in sedimentary basins. Many systems are available and the main issue is to decide which system are most appropriate to guarantee the delivery of the right information to the decision-makers in government and industry in the right form at the right time (and within budget).

The Marine Petroleum and Sedimentary Resource Division is developing a system to handle all aspects of resource evaluation from acquisition of data to distribution of products that illustrate resource characteristics. Many of the components of the system are in place and the challenge is to link them to allow data and information to flow seamlessly to produce appropriate products.

Documentation of basin resource evaluation methods provides the basic design of the system. Standard petroleum industry SIS software such as Petroseis, PEP, GEOQUEST, STRATLOG and industry standard relational databases such as ORACLE form the nucleus of the system. However, many other packages such as Arc/Info, MapInfo, MegaDrifter, ER Mapper and a number of gravity and magnetic modelling packages must also be evaluated and incorporated. In addition, AGSO will have to develop a system to ensure that all of the output from the software on a number of different hardware devices is concentrated on into a few key products that illustrate our knowledge of the resources in sedimentary basins.

PETROSYS MAPPING IN THE OTWAY BASIN: AN EXAMPLE OF GIS IN PETROLEUM-RELATED PROJECTS

Doug Finlayson, Marine Petroleum and Sedimentary Resources Division, AGSO, CANBERRA

Mapping subsurface geology and providing databases of related information is of crucial importance to the petroleum exploration industry and those charged with the management of resources associated with sedimentary basins. The Petrosys subsurface mapping system has been used for about four years on NGMA projects, including the Otway Basin Project which involved four institutions in Canberra, Melbourne and Adelaide. It was important to employ a seismic line mapping tool which was capable of being implemented on a number of different platforms, was widely accepted by industry clients and could be interfaced with other mapping and database tools. Negotiations with project partners were essential at the beginning of the project to determine common systems, formats and products. There is a steep learning curve on any new systems; computer staff working closely with project staff are important. Strategies for archiving and guarding against software company collapse are still not clearly defined.

AGSO'S NORTH WEST SHELF TECTONIC ELEMENTS DATABASE: A MAJOR MAPPING TOOL AND NASCENT GIS

Howard Stagg, Marine Petroleum & Sedimentary Resources Division, AGSO, CANBERRA

Since 1993, one of the prime planning, mapping, and interpretation tools in use in AGSO's Marine Petroleum and Sedimentary Resources Division has been the North West Shelf Tectonic Elements Database. This database, encompassing an area of more than 4 000 000 km^2 of the continental margin, and adjacent deep-ocean basins and onshore areas along the North West Shelf (NWS), contains a wide range of information within five broad areas:

Geological structure: faults (normal, reverse, strike-slip, transfer); depocentres; structural highs; hinges; continent-ocean boundary; sea-floor spreading magnetic lineations, fracture zones, and fossil ridges; anomalous oceanic crust.
Exploration: exploration and ODP wells; oil and gas field outlines and discovery locations; pipelines and production facilities; locations of dredge, core, heat-flow, and seismic refraction stations.
Onshore lineaments: aeromagnetic; gravity; Landsat; geological mapping.
Bathymetry: Contours at 500 m intervals from GEBCO bathymetric maps.
Geographical/political boundaries: coastline; reefs, state and seabed boundaries.

The database was developed using the Petroseis mapping software, and this is still the principal software platform. The database has also been ported to Arc/Info, primarily to increase its appeal to external users; however, full use of the GIS capabilities is not yet made.

We are now at the stage where a major effort needs to be made to transform this major mapping and interpretation tool into a genuine geographic information system that can be used to test geological and exploration models. It is intended to commence this process with a pilot study in the northern Carnarvon Basin during 1995. On completion of this pilot study, the GIS will be extended to cover the entire area covered by the existing NWS tectonic elements database. The development of this GIS requires effort in two main areas:

1. Additional information needs to be recorded for the tectonic elements already in the database: for instance the ages of movement on faults; age of formation of particular depocentres or structural highs.

2. Incorporation of information both from other interpretation projects within AGSO: particular examples include structure and isopach contour maps, palaeogeographic data, and petroleum systems data.

It is anticipated that the northern Carnarvon Basin pilot study will produce a working GIS by early 1996; extension to the remainder of the NWS will take place over the following 1-2 years.

PETROINFO: A GIS FOR PETROLEUM-RELATED DATA

Chris Parvey and David Palfreyman, AGSO

PetroInfo is a GIS for petroleum relevant data. Its rational in development was to centralise under one system spatial data, held by AGSO and other agencies, relevant to petroleum exploration. To date it holds data on approximately 30 themes as Arc/Info coverages. It is accessible to users via ArcView 1 on a Novell disk server.

New Zealand

GIS IN THE INSTITUTE OF GEOLOGICAL & NUCLEAR SCIENCES: WHAT & WHY

Peter R Wood, Institute of Geological & Nuclear Sciences, New Zealand

The Institute of Geological & Nuclear Sciences is the only dedicated geoscience research organisation in New Zealand. The Institute manages several NZ national databases that include diverse observational data collected from more than 100 years of geological and geophysical research by the Institute and its predecessor - DSIR. These databases include: geological field data; minerals; coal; earthquakes; marine and onshore geophysics; geomagnetics; geothermal; geochronology; landslides; palaeontology; petrology. These data have, naturally, geographic attributes and are being incorporated into GIS.

The principal objectives of GIS in the Institute are to improve accessibility, abstraction, integration and manipulation of the data contained. GIS applications and technology are evolving in the Institute, as they are around the world. Early systems were based on home grown products but these were generally difficult to maintain and upgrade. The Institute has made a major commitment to further develop its GIS capabilities. Arc/Info is the primary Institute GIS software, supplemented as necessary by Techbase, MapInfo, EarthVision, and ERDAS.

Geological mapping is a fundamental Institute activity. Some published geological maps have been digitised, including the 1:1 Million Geological Map of New Zealand, the first national digital geological coverage.

A revised edition of the 1:250,000 Geological Map of New Zealand is a major Institute GIS project (QMAP) - the production of a seamless national geological map and database. Data are being captured at 1:50,000. The setting up of this project is almost complete and production work has started, involving field data collection through to raster plotting.

Geophysical research is increasingly using GIS for managing and displaying very large datasets - such as a gravity coverage of the New Zealand Exclusive Economic Zone. Applications to sedimentary basin analysis and swath bathometric imagery are being developed.

The Geological Resources Map (GERM) is a NZ wide economic minerals database, accessed by GIS and available for research and commercial applications. It contains summary information on the geology, geochemistry and production for more than 10,000 occurrences of rock aggregate, metallic- and non-metallic minerals, coal, oil and gas, and thermal water.

Natural hazard mapping, analysis and zonation by the Institute (seismic, landslide, volcanic) is an area of applied research that increasingly uses GIS for developing hazard models for risk assessment. A number of clients, such as local authorities, insurance companies and large project developers require natural hazard GIS products for input to their GIS systems. Special project geological data, for hydroelectric investigations and urban hazard studies, are captured digitally at scales from 1:50,000 up to 1:1,000. Such surface geology is being integrated with digital topography and subsurface data (drillhole, seismic) to develop three dimensional models of lithology, structure, and permeability for application to problems such as groundwater and hydrocarbon flow and landslide susceptibility.

The Taranaki Basin Petroleum Atlas is a GIS product that integrates manual compilations and interpretations of the regional petroleum geology of the entire Taranaki Basin. The 50 Atlas sheets, which include geological structure, isopach, source rocks, play maps and reservoir potential, have been made fully digital from inputs out of GIS databases, spreadsheets, word-processors, and seismic processing software. Digital data from this project are to be used in 4D modelling next year.

Issues not yet fully addressed include improving data management (quality assurance, metadata, access), increasing user education and further developing Institute application tools.

New South Wales

RECENT DEVELOPMENTS IN GIS AND DATABASE IMPLEMENTATION IN THE GEOLOGICAL SURVEY OF NSW DEPT MINERAL RESOURCES

Peter Lewis & David Suppel, NSW Dept Mineral Resources

The Geological Survey of New South Wales operates a GIS system with Arc/Info and ER Mapper software. In addition some image processing is carried out using ILWIS. Several geoscientists use PC based MapInfo. Software packages have been acquired to allow conversion of 'coverages' to and from Arc/Info and MapInfo. PC and workstation versions of ArcView 2 are on order. No fixed policy has been established, however the current plan is to make Arc/Info and ER Mapper available to trained Departmental users for the preparation of the original digital files, and to distribute PC based versions of ArcView 2 for project use and personal customisation. Planning is well advanced for implementing a RDMS of geoscience data. Once established, the geoscience tables in the RDMS will be linked directly to Arc/Info.

Two programs are using GIS technology as a major component in their work plans, the Mineral Resources Audit and the Discovery 2000 Programs. Both programs are involved in assembling themes of geoscience and other data into packages of information using Arc/Info. Note also that in 1995 planning is underway by the Department's Cartographic unit to expand the production of maps using Arc/Info.

The Mineral Resources Audit Program began assembling data on project areas in late 1993 and a workstation based Arc/Info system was installed in December 1993. A major activity of the Program is to model styles of mineralisation and to assess mineral potential by spatial analysis. To carry this out the data has been 'value added' by the addition of interpretative items. The new items enable selection of features such as deposit styles, intrusive/volcanic types, depositional environments, tectonic settings and resource potential ranking.

Modelling of project areas is conducted to determine metallic, industrial and construction resources. Recent work has included a range of methods from the simple subjective to the measurement of probability and possibility by more advanced techniques, such as 'Weights of Evidence'. The Program is producing packages of specific regions, larger areas or provinces (e.g. the Lachlan Fold Belt) and ultimately a Statewide coverage. One product, the Lachlan Fold Belt Package is due for release by end of May 1995 as an ArcView 2 package, probably on CD-ROM.

The Discovery 2000 Program is concerned with acquiring information of value in determining prospectivity, particularly for significant metallic resources. Detailed airborne magnetics and radiometrics as well as gravity data are being acquired for selected areas. The available geoscience data is being assembled for each area. If necessary additional new data will be collected from activities such as drilling, age dating and whole rock geochemistry. The aim is to assemble a 'complete' GIS set of layers for review and re-interpretation of bedrock and covered areas.

The Mineral Resources Audit and Discovery 2000 Programs are collecting and standardising large volumes of data. An RDMS will be implemented in the first half of 1995. Data modelling of most geoscience themes is complete. The basic design is similar to the AGSO model and attempts where possible to use the same lookup and authority tables. A live link is to be created between the tables and Arc/Info and this requirement is being considered in the table design.

Tasmania

DIGITAL GEOSCIENTIFIC DATA IN TASMANIA - CURRENT STATUS AND FUTURE DIRECTIONS

Michael Roach, Data Management Group, Tasmanian Geological Survey

A project-driven approach to digital geoscience data acquisition has been successfully applied by the Tasmanian Geological Survey. This pragmatic "bottom-up" strategy for the development of a corporate data structure has resulted in rapid progress which would not have been possible with a traditional "top-down" design approach.

Geoscientific data is extremely diverse and includes both quantitative and qualitative information. The challenge in developing data structures for digital geological information is to preserve the essential content of the existing analogue data in a form which enables diverse and efficient query and manipulation in the GIS

Data structures developed by the Tasmanian Geological Survey to encode geological map information and geochemical data are described. The geological and geochemical data structures both encode attributes in a series of related tables which employ one-to-many and many-to-many links to efficiently and accurately represent original data relationships.

Victoria

THE PUBLIC FACE OF GIS

Brian Wright, Manager, GIS & Client Systems, Energy & Minerals Victoria

The Department of Energy and Minerals is the recipient and custodian of vast amounts of geological exploration and other earth resources data which is collected by Departmental resources or reported to it by industry under the terms of various Acts. This information may be in hardcopy or digital form and is widely used by exploration companies and consultants to the industry. The exploration industry considers it to be the role of government to provide the basic regional, basin and accrued information to entice private industry to invest in the exploration and development of the state's rich resources.

Various manual and computer based systems have been developed by both government and commercial enterprises to provide access to this type of information in other Australian states and overseas. Departmental research clearly indicated the need for a state of the art information system to deliver this information to industry and as a result the Department embarked on an intensive research and development project in 1988.

The Geological Exploration and Development Information System (GEDIS) represents the pinnacle of the Department's information systems. Developed in-house using the GENAMAP mapping system and INGRES relational database as a foundation for purpose built applications, GEDIS is a Geographic Information System (GIS) providing an integrated solution that supports government policy aimed at encouraging mineral and stone exploration in Victoria. GEDIS improves access to a range of government and private data required by clients in the planning and conduct of exploration programs, resource assessments, tenement management and other resource applications.

It is clear that Victoria is competing for industry investment with interstate initiatives as well as other countries who provide significant incentives to attract investment from the mining industry world wide. Clearly the GEDIS information system is a highly valuable attraction to mining industry investment in this state, particularly in the field of exploration.

GEDIS aims to provide a method for explorers to access information using a simple, graphical user interface which combines both graphical and attribute data. The system also aims to provide the means for capture, maintenance and retrieval of all classes of data required by the Department's staff. GEDIS supports the State Minerals Policy aim to "improve opportunities for the minerals industry to contribute in an environmentally sensitive manner, to Victoria's economic recovery and the provision of job opportunities".

GEDIS provides access to both spatial and textual data that is managed by purpose built systems designed and developed in-house. The spatial and textual data are maintained separately in most cases with the integrity of data being ensured by the procedures in place. The management of this data both ensuring data quality and capturing new data is a major task.

A Graphical User Interface (GUI) has been developed in house which combines the spatial and textual databases and allows clients to query on either. Results are displayed both graphically and textually in windows on the terminal and results can be further interrogated in either environment to further refine the query.

Paper outputs take the form of plots of user defined areas and matching reports for selected attributes from the textual database. The inquiry system (GINGER) is available at the public inquiry counter, two regional offices and to many staff in Melbourne.

GEDIS is the manifestation of the Department's business philosophies for data and information as a basis for sound business development. It is also in the mainstream of current computer technology and a major thrust of the Government policy relating to the mining industry. GEDIS is not just a technical plaything. Access is widely available to the Department's staff and it is the major information source for the Department's "walk up" clients. GEDIS represents the public face of GIS.

South Australia

SELECTED ISSUES IN GIS AT MINES AND ENERGY - SOUTH AUSTRALIA

Neil Sandercock, Minerals & Energy, South Australia

The development of GIS at MESA has progressed steadily from simple digital mapping in the 1980s to a substantial investment in data and its management and utilisation into the 1990's. Many issues determine the usefulness of geographic data when brought together within a GIS. These include the rigour of the spatial data capture, the establishment of the relationships between spatial features, the delivery of the data to its users and the documentation of its limitations. MESA has developed rules to assist in the implementation of its GIS. The essence of these rules is to provide users with the data they require in the format they require and within an acceptable time.

Western Australia

REGIONAL GEOCHEMICAL MAPPING USING GIS

Stephen Bandy, Project Manager GIS and Kathryn Smith, Geological Survey Division, Dept Minerals & Energy WA

The Geological Survey Division of the Department of Minerals and Energy (WA) has been allocated $3.75 million over the next three years, with $1.25 million in 1994, to complete a systematic regional geochemical mapping project.

In 1994, the Project involved the sampling and analysis of drainage sediments and the mapping of superficial materials (regolith) on four 1:250 000 scale map sheets. One sheet is now complete with the other three in various stages of completion. The sampling ratio is approximately one point per 16 km^2, representing a total of more than 4000 points over an area of 64 000 km^2.

One broad objective of the Regional Geochemical Mapping GIS Project is to store data collected in the field in such a way so as to permit its use within a GIS. The database is an integral part in the production of hardcopy maps and digital information. These products include digital data extracts and presentation of data in hardcopy form including the regolith, site location and the results of chemical analysis of 48 elements.

The 1:250 000 scaled maps can, in conjunction with other base information, be used in exploration programs for the identification of specific areas of the state with potential for undiscovered mineralisation and the provision of base chemical information for use in agricultural and pastoral activities.

Queensland

MERLIN: A CORPORATE APPROACH TO INFORMATION MANAGEMENT

Geoff Baisden, Principal Graphics Project Officer, Dept Minerals & Energy, Queensland

MERLIN is a concept where all non-confidential departmental mineral and energy resource information is accessible through a computerised interface, and easily available in combinations and permutations limited only by the imagination of the inquirer.

A major impact on the way spatial information is managed and used by government agencies and industry has been brought about through the emergence of Geographic Information System (GIS) technology. MERLIN, the system, takes full advantage of this technology by allowing the integration of different data sets through their spatial location and to enable interrogation of associated attribute data to highlight areas of interest.

To allow easy access, MERLIN provides an application specific graphical user interface. All of the functions of the system can be initiated through this interface including data entry, maintenance and interrogation. Output from the system is available in many forms including graphical plots and textual reports.

The Mining Tenures Data Base, Phase 1 of MERLIN, commenced in 1988 is now fully operational statewide in all departmental offices. In continuation of the theme of corporatising departmental information, development of Phase 2 of the MERLIN system, the Geoscience and Resource Data Base, was commenced in mid 1990. Development of this phase was completed in the second half of 1994 and data will be progressively captured through 1995 before being added to the MERLIN system.

2. INDUSTRY APPLICATIONS

SPATIAL DATA MANAGEMENT FOR GIS

Colin Farrelly, Computer Services Manager, Australia & Asia, Exploration Dept, BHP Minerals Pty Ltd

Successful exploration and mining in the 1990s depends increasingly on the ability of our geoscientists and engineers to efficiently and effectively acquire, store, manage, analyse and interpret an increasing amount and variety of multi-dimensional spatial information.

Improvements in computer hardware, operating systems and database management software are allowing us to efficiently handle the quantity and complexity of information, while improvements in graphical applications packages are allowing us to effectively analyse and interpret the data.
The increased use of such technology is being driven by increasing requirements to more rapidly find and develop world class deposits. This is despite such deposits being technically more difficult to find in well hidden or inaccessible locations, and being more difficult to develop due to increasing requirements from customers, regulatory authorities and company economic imperatives.

BHP Minerals uses a combination of various data management systems together with interactive graphics software and hardware to handle the large amounts of data required for technical decisions in resource exploration and development. Data management software includes: Oracle, Microsoft Access and a number of systems attached to particular applications packages. The applications software used to analyse and interpret spatial data includes: GIS, statistics packages, image processing systems and 3D visualisation and modelling packages.

Both the business requirements and the emerging technology have lead to a vast increase in the volume of data which needs to be effectively managed and analysed. The spatial context of the data has come to dominate both the management and analysis of most of our large data sets.

Database Management is seen as a distinct process between data acquisition and data analysis, and it usually occupies most of the effort in the computer processing of the data. The use of a variety of different packages to meet any given technical objective is now common, and it has lead to an increased emphasis on the methods of data conversion. Improvements in standard methods of data transfer and the direct attachment of databases to applications packages is greatly increasing our ability to use the right software for the right job.

The trend for some time has been towards third party database and applications software, although there is still a significant amount of work required to build database applications and to integrate the database with graphical applications systems. This development process continues to be a challenge to ensure that large systems can be built effectively to suit the user requirements with a minimum amount of redevelopment.

The model for the optimum management of spatial data varies according to the specific requirements, but the trend is towards decentralised project databases on PC platforms which can link to centralised strategic systems on a Unix platform.

Both the relational and the graphical approach to handling spatial data results in faster and better methods of data validation and data analysis. When coupled with real-time interactive methods of GIS visualisation and modelling, it facilitates decisions which are more informed, more timely and more easily sold to management.

The trends over recent years are clear, and such methods are quickly becoming a normal part of every stage of the exploration and mining process.

EXPLORATION DATA MANAGEMENT ON A MINERAL PROVINCE SCALE

Simon Beams, Terra Search Pty Limited, Townsville

Terra Search is on the leading edge of the compilation, manipulation and visualisation of mineral exploration data in Australia. We have built a database of over 500 000 surface and drilling samples over some of the most intensively explored mineral provinces including Mt Isa Block (AMIRA Project P413), Ravenswood Block and the Drummond Basin. Data is currently being compiled from the Lachlan Fold Belt for the NSW Dept of Mineral Resources and from Eastern Queensland (Yarrol Block) for AMIRA P413A. These compilations have been facilitated by Terra Search's research and development of the Explorer II data management system which handles the capture, storage and retrieval of a wide range of exploration data. Such a uniform relational database format has wide industry acceptance and could become a standard for digital reporting and data transfer in a GIS environment.

USE OF A GIS TO QUANTIFY GOLD PROSPECTIVITY FOR THE SOUTHERN CROSS GREENSTONE BELT, WESTERN AUSTRALIA

Carl Knox-Robinson, David Groves & David Robinson, Key Centre for Strategic Mineral Deposits, Department of Geology and Geophysics, University of Western Australia

The Yilgarn Block of Western Australia is world-renowned for its wealth and abundance of gold. Since the metal was first discovered late last century, over 2,000 deposits have been found, with production ranging from several kilograms to over 1,300 tonnes from the famous Golden Mile in Kalgoorlie. The majority of known gold deposits are located in areas of outcrop, and although outcrop constitutes less than 10 percent of the surface area, only a few deposits have been discovered in areas of non- outcrop, even with the aid of modern geophysical and remote sensing techniques.

Although superficially diverse in terms of host rock and style of mineralisation, most gold deposits in the Yilgarn Block share several common features. The majority of the deposits are structurally controlled, and from isotopic studies, fluid inclusion data, and available geochronology, it is apparent that they formed as a result of a single Yilgarn-wide mineralisation event. Based on this realisation, and equipped with a large database of known gold occurrences, it is possible to use empirical techniques to identify prospective areas of non-outcrop which can be targeted for further investigation. At the Key Centre for Strategic Mineral Deposits at The University of Western Australia such a methodology has been developed for use within a Geographic Information System (GIS). Suitable geological map data are digitised into the GIS, including the position of known gold deposits. A subset of these deposits are then selected, and their spatial association with surrounding geological features (e.g. faults, dykes, and lithological contacts) are examined, one theme at a time. If a spatial association is identified between these deposits and a particular type of geological feature, the relationship is quantified into a map showing areas of low and high favourability. Several of these maps are ultimately integrated into a single prospectivity map, which highlights areas similar to those known to contain gold deposits. The prospectivity map is tested for applicability using the subset of deposits which were not used in the construction of the map.

The methodology has been applied successfully to the Southern Cross greenstone belt of the Yilgarn Block, using conventional geological map data at a scale of 1:100,000. This study indicates the regional-scale importance of major deformation zones and, in particular, lithological contacts between rock types of contrasting rheology. Furthermore, it is evident that the orientation of lithological contacts and other deformation zones can significantly influence where large gold deposits are likely to be sited on a more local scale. Preliminary investigations shows that, with the integration of other data sets such as remote sensing, geophysics, and geochemistry, the predictive capacity of such prospectivity maps can be improved significantly.

GIS APPLICATION TO PROJECT PRESENTATION

Ken Moule & Harvey Ryan, Exa-Min Resource Industry Consultants, BRISBANE and Rod Dawney (Ausmec)

The paper considers the changing demands placed on data management systems as projects progresses from grass roots exploration to development, and the advantages of managing this transition through a GIS system. An integrated GIS approach prevents the traditional separation between management style 'cartoon' presentations and underlying technical data.

Rod Dawney will present the first part of the paper. He will relate a recent experience with a stream sediment sampling program in Pakistan where MapInfo was implemented as an interpretational tool but had enormous impact as a data presentation system. Having all data available at his fingertips allowed Rod to provide an on-site presentation to senior government officials with enough detailed backup to also satisfy their technical colleagues.

The second half of this paper considers the extensions required for a more advanced project. Harvey Ryan will present a recent Exa-Min consulting assignment carried out for a proposed silica operation near Bundaberg, Queensland. A desktop mapping application (MapInfo) was adapted as a presentation medium for marketing of the prospect to the investment community.

The GIS system provides a graphical pointer to a full range of prospect data including surface mapping, drill results, tenement information, resource estimates and representations of project infrastructure. The database includes scanned photographs and bit map images of important documents. This project required coding of extensions to the standard GIS system to support data management and ensure consistency of graphical style.

Functions were developed to ensure consistency between the GIS system and the underlying database. Geological 'objects' such as faults, geological boundaries and exploration samples were defined with database object codes and graphical style corresponding to the Aust IMM mapping standards. This reverses the normal computer based approach where these would be considered primarily as CAD entities with attached graphical attributes.

Having established a table of geological objects it was a simple extension to automate the inclusion of a legend on plotted output. Further extensions support production of sensibly scaled output with scale bars and standard title blocks. We have added a high level CAD presentation tool to what is traditionally viewed as a data analysis system.

GIS is presented as a key tool in reducing the data fragmentation that traditionally affects large projects with core data duplicated in CAD systems, spreadsheets and word processor documents as well as the geological database. GIS pointing complements the emerging client-server database environment by providing graphical ties to all types of project data.

GIS AS A TOOL FOR GEOLOGICAL MAPPING IN NORTH-EAST NSW

Adrya Kovarch & David Moore, GeoMapping Technologies Pty Ltd, and Peter Flood, Dept Geology & Geophysics, Uni. New England

A Geographic Information System was developed to revise the 1:250 000 geological maps of the Warwick and Tweed Heads area in New South Wales.

Arc/Info was used to perform all the cartographic tasks for the project and TNT mips was used to integrate and analyse various data sets such as, airborne radiometric and magnetic data, a Landsat TM scene and topographic information. These data were used to assess the accuracy of geological boundaries and structures. The digitised geological boundaries and structures were assigned AGSO line symbol codes and generalised to 1:100 000 and 1:250 000 scale, annotated and printed.

The GIS also included a comprehensive database, containing geological rock types, mineral deposits, marine and plant fossils and a variety of additional geological information.

The GIS proved an efficient tool for geological data management, analysis and cartography and represents a more valuable product than the printed maps, providing a flexible system for the updating, analysis and dissemination of the geological information it contains.

GIS IN MINERAL EXPLORATION

John Parker, Geosurveys Australia Pty Ltd, South Australia

The aim of this paper is to demonstrate the use of GIS in different stages of mineral exploration using a case study on Eyre Peninsula with reference to one or two other cases:

- regional evaluation of a prospective area using geological survey data
- compiling additional regional data from open file geological survey reports (eg company envelopes)
- regional analysis and target generation based on the intersection of favourable geology, known mineralisation, aeromagnetic domains, structure and existing geochemistry
- collecting data in the field
- prospect scale compilation of field notes, geochemistry, ground magnetics etc and generation of maps and reports
- prospect scale analysis of field and other data

3. MODELLING

INTEGRATION OF GIS AND HYDROLOGIC MODELS

Dean Djokic, Andrew Coates, and James E. Ball, University of New South Wales

Geographic Information Systems (GIS) provide many capabilities for hydrologic modelling that were traditionally performed by hand. The ability to directly integrate GIS technology with hydrologic models promises a significant increase in modelling consistency, accuracy of data extraction and preprocessing, and ability of data exchange between different models. Although the promise is there, actual integration process requires great care and is full of traps. Application of GIS for floodplain delineation is used to demonstrate the benefits and pitfalls of GIS-model integration. A case is made for development of a generic hydrologic data exchange format that would enable easier model to model and model to GIS data transfer.

APPLICATIONS OF THE AUSEABED MARINE GIS/DATABASE IN ENGINEERING AND NAVAL ACOUSTICS

Chris Jenkins, Ocean Sciences Institute Geology & Geophysics, University of Sydney

OSI has designed, developed and populated a GIS database of the seabed for the Australian maritime area -AUSEABED. The structure includes information on seafloor topography, sediment types, engineering and acoustic physical properties, natural and contaminant geochemistry, near-bottom currents, acoustic and visual imagery, and rock/reef/sandwave areas.

Three primary technical goals for the project have now been met through deliberate design of the data structure: (i) to deal in an open and adaptable way with seabed point/trackline/areal data from diverse data sources; (ii) to build specialised tools/applications for handling marine data; (iii) to be readily exportable to a variety of GIS and relational databases for specialist applications in research and industry. A focus on original 'point' rather than polygonized data gives the database has the highest degree of adaptability in modelling applications and assimilation of new data.

The raw AUSEABED dataset can be enhanced and extended through a set of modelling processes to bridge data gaps or to produce thematic maps and statistics as aids to engineering feasibility studies, offshore management policy and programs of general research. Two examples are provided: (i) seafloor stability for small objects; (ii) sonar underwater detection performance (which is dependent on seafloor sediment type) for a navy ship at any location around Northern Australia. The examples highlight the promise of GIS in marine activities, but also the necessity still in modelling to use a variety of software application packages - native programming, GIS and Relational Databases.

INTEGRATION OF GIS AND MODELLING IN THE AGCRC

Simon Cox, CSIRO Exploration & Mining, WA

The Australian Geodynamics Cooperative Research Centre (AGCRC) is engaged in a substantial new synthesis of the geodynamic history of Australia. This includes both compilation of existing models, and new interpretations of critical areas. Central to the project is the use of computer based modelling and visualisation techniques. The aim is to capture and present the outcomes of this work in an interactive digital environment, and make this available to the exploration community.

GIS will play an important role. Yet many important functions for geodynamic modelling are not available within GIS managers, particularly 3D capabilities. These may be covered, however, by existing commercial and non-commercial software, by tools under development within the AGCRC and collaborating and related organisations, and by as-yet unannounced future packages and specifications.

Stitching these together in an effective way is a significant challenge. There are a number of important considerations. For example, it will be necessary to service users with different levels of competence: while advanced users will want to take advantage of the native interfaces of the various applications, casual users will need an intuitive interface with only summary functionality. Integration with related information services, such as @ngis, will be a basic requirement. It is critical that metadata (describing details of the underlying observations and the modelling and interpretation methods used to derive higher level entities, by whom) be available to allow a user to determine their confidence in a particular feature or component. Controlled access to commercially sensitive datasets will need to be managed. And since geology is a historical science, the incorporation of time into GIS representations needs to be carefully thought out.

Some important data organisation issues impinge on the system acting as an integrated package. Data-model transformations, as well as simpler reformatting, need to be accommodated in order to share information between the components. Although SDTS provides a basis for 2D representations, this is far from complete for the geological applications here. Work is underway in several forums aimed at producing a superset of the various data-models in use together with tools for conversion between these.

Finally, although adherence to standards at some level will be essential in achieving such a system, it is important that these do not act as a straight jacket, but are flexible enough to ensure that the best technological and algorithmic developments can be taken advantage of easily. The use of standard specifications such as http/cgi and CORBA should facilitate this and avoid automatic obsolescence. A prototype interface based on the WorldWideWeb has been developed.

SEMANTICALLY-SPECIFIED GEODATA MODELS

Bohdan Durnota, Department of Software Development, Monash University

Recent geodata models such as the Open Geodata Interoperability Specification (OGIS) and CSIRO's data model for Geoscientific Spatial Information Systems have been increasingly using a more formal specification style, and the use of object-orientation. However, there still remain parts of the domain for which a semantically defined data model has not been worked out, nor have any associated operations been semantically defined.

Building on our experience in using the Object-Z object-oriented formal specification language to define a number of terrain features in digital elevation models, we apply this technique to the geodata domain. We construct a simple formal specification for certain geological cross-sections, and then indicate how some interesting kinematic operations such as faults can be semantically defined.

This paper illustrates how the combination of formal specification techniques and object-orientation can lead to precise and unambiguous data models within the geosciences. We also discuss issues such as tool support and end-user interfaces to such formal geodata models.

SIMPLIFYING RELATIONAL GEOLOGICAL DATABASES BY GENERALISATION

Roderick J. Ryburn, AGSO, CANBERRA

Unless database designers are careful, the complexity of geological subjects can result in data models that are too complex to be implemented with available resources. Generalisation involves a search of the logical data model for entities that can be grouped into super-entities occupying single tables in the physical model. Carried out assiduously, generalisation often reduces the number of tables needed by more than a half. Illustrations are taken from the 'rocks' and 'sectholes' parts of AGSO's OZROX field geology database.

4. POLICY

LEGAL REGIMES IN ACCESS TO GEOGRAPHIC INFORMATION

George Cho, School of Resource, Environmental & Heritage Sciences, Uni of Canberra,

A traditional view of information is one of ownership and control - both of which imply restrictions to access. A *laissez-faire* view highlights open access and free dissemination of information. Each of these reflect particular institutional settings and policies in place to protect 'public goods'. This paper explores legal regimes governing access to geographic information collected by public agencies. Cross-national comparisons are made to give principles and practices and highlight the legal-policy responses. The legal issues emerging from these different regimes are discussed including an outline of policy implications.

TOWARDS A NATIONAL POLICY ON THE TRANSFER OF GEOGRAPHICALLY-REFERENCED DATA

David Berman, Director Information Services Division, AGSO, CANBERRA

- Policy setting - ANZ Land Information Council/Commonwealth Spatial Data Committee
- Government Initiatives - AARNet: ASTEC & BSEG Reports, communications deregulation

- Australian National Geoscience Information System - @ngis
  - results of the @ngis client survey
  - AGSO World Wide Web Internet server, and potential for @ngis GIS/spatial access

5. STANDARDS & DATA EXCHANGE

SDTS (AS/NZS 4270) - WHERE NEXT WITH THIS AUSTRALASIAN STANDARD?

Richard Hume & Don Miller, AUSDEC, Victoria

The Spatial Data Transfer Standard has been adopted by Standards Australia and Standards New Zealand as AS/NZS 4270.

Where next with this Australasian Standard? This paper discusses issues associated with the adoption of the standard by GIS users in Australasia. These issues include the introduction of profiles (subsets) of the standard, the current status of the development of dictionaries, and what software will be available. Another important related issue is what other geo-spatial transfer standards will be in use in Australasia and how these standards will coexist.

The paper also looks at the ease of creating a SDTS transfer. Major GIS systems are developing SDTS translators which will enable the easy export of SDTS transfers. This is illustrated with a discussion of how one exports a SDTS transfer through the GIS ArcInfo.

Where to from SDTS? The International Standards Organisation has established a committee, ISO/TC 211 - Geographic Information/Geomatics that will include the transfer of geographic information. This committee will need to integrate a number of international geo-spatial transfer standards which includes SDTS. Standards Australia is to play an important part in this committee.

GEOSCIENTIFIC FILE CONVERSION WITH INTELLIGENT TRANSLATION FOR INTEGRATION WITH CAD PRODUCTS

Fred Garside, Corporate Montage, New South Wales

Developers of GIS systems tend to concentrate their efforts on the data-storage and retrieval features of their products. Facilities for identifying, extracting, and *exporting* graphics to other systems are given a low priority, while the *import* of graphics from CAD or specialised Geoscience applications is usually impossible.

This paper provides a brief description of some of the graphical formats encountered, with some hints on how best to move them into and out of a GIS system.

GIS Formats covered include Arc/Info CGM formats (for export), and Landmark, Zycor, Petrosys, GeoQuest CGM formats for imports.

THE AUSTRALIAN STANDARD DATA MODEL FOR THE GEOSCIENCES

Richard Hume & Don Miller, AUSDEC, Victoria

An Australian Standard data model is being developed for the geosciences. The data model, called the Geoscience Data Model, will provide a definition of geoscience data and the relationships between this data. This data model will provide a common basis of understanding for geoscience data through a common language and a common structure for geoscience information.

The requirement for a standard geoscience data model has been recognised in Australia for some time. A working group of the Australian Government Geologists Database Policy Advisory Committee began investigating geoscience data models in 1991. This led to their strong support for the Geoscience Data Model project.

The project is a joint government and industry funded project and is managed through the Australian Mineral Industries Research Association, AMIRA.

The Geoscience Data Model will be particularly important to both government agencies and the mineral industry as each are developing increasingly complex databases of geoscience information.

THE GEOCENTRIC DATUM OF AUSTRALIA - A CO-ORDINATE SYSTEM FOR THE 21ST CENTURY

Jim Steed, Australian Surveying and Land Information Group

The Intergovernmental Committee on Surveying and Mapping (ICSM) has adopted a new co-ordinate system, the Geocentric Datum of Australia (GDA) to be implemented by the year 2000. This will see a change from the locally defined Australian Geodetic Datum (AGD) to a global co-ordinate system compatible with that used by the Global Positioning System (GPS). An overview of co-ordinate systems in Australia is given to introduce the technical specifications of the new GDA and techniques which may be used to convert existing data sets are proposed.

SCIENTIFIC DATASET CATALOGUES

Shawn Callahan, Sybase Australia Pty Ltd, Canberra; and Dave Johnson, EarthWare Systems, Canberra

Many catalogues or metadatabases of scientific datasets exist. Through their development and use we have gained considerable knowledge of what makes one more successful than another. One key lesson learnt is the importance of catering for people and organisational issues. Questions like how to motivate people to properly document datasets or how to provide access methods that enable users to rapidly find relevant information are fundamental. The selection of database environments, on the other hand is secondary.

There is a parallel development of metadatabases throughout a wide range of scientific and non-scientific disciplines. Considerable research exists, for example in the information science field, on how people use catalogues and the psychology behind their actions. In the rapidly developing area of data warehousing metadatabases are a key component. These experiences are directly applicable to spatial metadatabases for scientific datasets and we should capitalise on them.

This paper outlines some of the characteristics we believe are essential in developing a successful metadatabase and how it is used in an overall information management strategy. In addition, ideas from the information science and data warehousing fields are introduced to add a new perspective. Finally we describe some new ways of presenting information that take advantage of the merging multimedia capabilities.

6. R & D APPLICATIONS

AN INTEGRATED SPATIAL INFORMATION SYSTEM WITHIN THE COOPERATIVE RESEARCH CENTRE FOR AUSTRALIAN MINERAL EXPLORATION TECHNOLOGIES

Bob Gozzard[1] and Don Hunter[2]
[1]Geological Survey of Western Australia,
[2]CSIRO Division of Exploration and Mining, CRCAMET

The Cooperative Research Centre for Australian Mineral Exploration Technologies (CRCAMET) has, as a primary objective, the dramatic improvement of airborne electromagnetic (AEM) technologies for exploration in areas of inhomogeneous conductive regolith cover. To help achieve this goal, the Centre is establishing a comprehensive integrated spatial information system with links between its GIS, RDBMS, image processing systems and the more sophisticated 3D modelling and visualization tools. A particular challenge to CRCAMET is the requirement to examine 2D/3D section/volume data (for example, EM conductivity-depth sections or volumes, drill holes, modelled geology) in conjunction with 2/2.5D spatial data (for example, regolith maps, radiometrics, magnetics, topography). The benefits of integrating datasets from disparate sources arising from the synergistic use of information systems technologies provide opportunities for improved data analysis and cartographic output. However, increased emphasis is placed on issues relating to the design of the databases, database management and an understanding of the problems and opportunities associated with the management of the system.

USING GIS FOR MINERAL POTENTIAL EVALUATION IN AREAS WITH FEW KNOWN MINERAL OCCURRENCES

Lesley Wyborn[1], Robyn Gallagher[2] and Terry Mernagh[1]
[1]Australian Geological Survey Organisation, CANBERRA, [2]GISolutions, Canberra

Geological agencies are increasingly being asked to participate in land use disputes to identify what the mineral potential of a region is, and to put a dollar value on the mineral wealth contained therein. As many disputed areas to be evaluated contain only a few occurrences or deposits, traditional statistical methodologies developed for the evaluation of the mineral potential of a region are not really applicable. Most statistical methodologies require the presence of a reasonable number of occurrences to be able to generate a valid assessment of the geological factors surrounding a group of deposits or occurrences. For this reason, we have chosen a conceptual approach for mineral potential evaluation in areas with few known mineral occurrences that relies on 3 separate, but integrated steps:

Step 1: involves developing a knowledge of Australian ore deposits as parts of regional scale 'mineral systems' in which the essential ingredients considered necessary for the formulation of a particular deposit type are expressed in terms of criteria mappable digitally within a GIS. Ore deposits need to be considered first as regional to district scale 'mineral systems', and then broken down into local, district and regional scale mappable criteria. The 'ingredients' considered essential to the formation of a deposit (*e.g.*, oxidised fluids, temperature, host rock composition) must also be translated into features that can be displayed within a GIS (*e.g.*, alteration zones, metamorphic grade, presence of reactive rock types, etc.). Within a 'mineral system' it is possible to apply 'ore deposit models' to search more specifically for known deposit types.

Step 2: entails the development of high quality geoscience GIS packages that express these mappable geological criteria as searchable attributes.

Step 3: comprises the development of methodologies for analysing the above GIS packages for mineral potential that does not rely on the presence of a minimum number of deposits present so that the resultant analysis can be regarded as statistically valid. The GIS analysis techniques developed have three different, but complementary methodologies. The first methodology is essentially an expert system that relies on a digital database of characteristics known to occur around major mineral systems and deposit types. The second methodology allows the user to interactively develop maps that highlight areas considered to have potential to host mineral deposits. The third methodology examines zones around known areas of mineralisation (or anomalous areas considered to have potential) and then determines the specific geoscientific expression of these areas in all themes within the GIS.

LANDSTAR AN AUSTRALIA WIDE REAL TIME DIFFERENTIAL GPS SYSTEM FOR GIS DATA CAPTURE

Robert Holloway, Racal Survey Australia Limited, GALCATTA

The Global Positioning System (GPS) has proven to be a cost effective method for positioning and locating areas of geological interest for input into Geographic Information System (GIS) databases. For some applications the purposely degraded level of accuracy by the US Department of Defence (DoD) under its policy of Selective Availability (SA) does not meet the requirement of some users. Differential GPS techniques are available which counteract much of the effects of Selective Availability and signal propagation errors through the atmosphere. These methods usually require the user to set up a base station on a known point with radio communications to a rover or post-processing the combined data at two sites after the event.

The Racal LandStar Differential GPS service provides differential corrections broadcast Australia wide by the Optus geostationary satellite in the industry standard format RTCM SC-104 to any user equipped with a small, portable LandStar receiver.

Towards Integrated Spatial Information Systems in AGSO - an Overview

David ML Berman
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There is an old joke which goes along the lines of "how do you get there from here" ?
The punchline usually states something like "you can't".

Well these days, with good GIS software, a georeferenced database, using a known datum, an understanding of scale, and a military GPS, there is a good chance that you can, or will soon be able to get "there".

But that is not the issue. The issue is that it's a pity you came this way in the first place. It would have been so much easier if you had bypassed this spot.

"This spot" is usually a point in a multidimential space consisting of organisational culture, technology infrastructure, access to data, and intellectual models, with social, political and economic constraints.

That is, AGSO is "here" because of where it came from and various forces it responded to - both deliberately and by chance, driven by environmental factors. Each organisation's "here" is unique. There are many valid "heres". Some of these "heres" are increasingly capable of establishing virtual links with each other. Higher dimensions - such as @ngis - are being envisaged to manage this hyperspace.

Hopefully, through attending a meeting such as this, you will get a feel for various "heres". This should then enable you to identify a more desirable "there" for yourself or your organisation, and better equip you to assist the navigation process.

So I am briefly going to outline the "here" of AGSO with respect to Spatial Information Systems (SIS) developments.

SIS in AGSO has a background of a set of independent operating Programs relating to different disciplines - or industry groupings.

Each has its own historic data collection, storage and product development approaches. However, there has been a growing desire and need to rationalise, corporatise, and integrate the data and supporting technology, particularly over the last 5-7 years.

AGSO's approach to SIS is shaped by its organisational role:

- New mapping - integrated datasets underpinning industry exploration
- Environmental geoscience & hazards datasets - contributing to ESD
- Custodianship of national geoscience databases.

A set of management, technological, project and corporately driven initiatives are identified, to illustrate how AGSO's strong SIS capability has come to be:

AGSO Management Initiatives

1988 Set up a specialist GIS technology and Applications group - NRIC

1989 Policy Initiative - New generation mapping - integrated datasets; digital maps for NGMA.

Decision to adopt digital cartography.

1990 Information Systems Study:

- An integrated spatial / mapping facility
- An organisation-wide network
- Data Management, custodianship
- Database Administration

1992 First GIS in Geosciences workshop

1993 Re-focussing of AGSO - Richards Review

AGSO Technology Initiatives

1990 adoption of an open systems environment:

- a common TCP/IP ethernet
- corporate facilities SIS management
- pilot data integration projects:
    - Arc/Info access to Oracle point data
    - integrating remote-sensed (raster) data with GIS (point, vector polygon)
- adoption of desktop client tools for browsing and querying datasets

1991 move to networked servers - distributed data processing model

1992 upgrade of seismic processing and analytical capability

redesign geophysical data processing and modelling software

1993 Oracle database administration / security

AGSO Project Initiatives

1989+	Various GIS projects, such as Shark Bay, Eastern Goldfields, Mt Isa Continuing population of project and national geoscience databases
1993	Standardisation on key SIS packages: • Microstation • Arc/Oracle • Petroseis • Intrepid • ER Mapper
1994	GeoQuest - seismic data interpretation Data transfer issues between packages being solved - eg Arc / Microstation, postscript

AGSO Corporate Initiatives

1994 Corporate standards being addressed:

- map design, production
- mass storage system
- metadata definition

1994 Recognition of external client data needs

- formats - ArcView, MapInfo, CD-ROM

- access to data - @ngis

1992-5 Corporate Oracle database structures matured and interlinked

- GGDPAC data standards & database technology exchange

1995+ Planning for high bandwidth applications & technology turnover

GUI-fication of applications, Oracle interfaces

Appointment of a corporate GIS manager ?
- (corporate standards, procedures, planning, systems integration, applications support)

CREATING MINERAL PROVINCE GIS PACKAGES - ISSUES, PROBLEMS, SOLUTIONS, AND OPPORTUNITIES.

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ABSTRACT With continuing software developments in Geographic Information Systems (GIS), it is becoming increasingly obvious that the capacity of GIS to integrate and analyse data can now exceed limitations imposed by the quality of primary digital data that can be incorporated. In the geological community, the calibre of GIS packages developed, and the time taken to prepare them, is being limited by issues such as the varying quality of the digital data sets that are available (including maps). More often than not, data quality relates to the diverse ways in which these primary data sets are captured and then documented. Care taken in the initial stages of data capture, and the effort put into data validation and ensuring internal consistency between different themes[1] can determine the quality of the final integrated GIS package, which in turn dictates how effective the package will be in metallogenic analysis. The major issues that constrain the creation of effective national geoscience GIS packages are the gross lack of uniform national data capture, data transfer and data storage standards. There is also the issue of the need for geological training that emphasises the importance of validated digital data sets. If some attention is given now to addressing these issues, then comprehensive national digital geoscientific data sets will be an achievable goal giving the geoscience community at large the opportunity to make valid contributions to national issues such as environment, agriculture, and human health.

1. INTRODUCTION

GIS has been defined as '*A decision support system involving the integration of spatially referenced data in a problem solving environment*' (Cowan, 1988). For most geological applications the capacity to integrate spatially referenced data within GIS is not easy, due to disparate and diverse data sets, and the lack of digital data standards. There is a cry for more powerful computers and software to facilitate the development of geoscientific GIS packages and also to enhance their analytical capabilities. None-the-less, some of the limitations experienced in compiling a GIS are not related to the potential of the computing systems being used. Instead, the quality of the GIS and its capacity to integrate diverse data sets is directly proportional to both the quality of the data that are being incorporated and the care that is taken in the initial stages of data capture and integration. In many cases, as the data sets being integrated within a GIS are derived from public domain sources, the absence of national uniform standards of digital data capture and data documentation is rapidly becoming a major issue in the development of new geoscience GIS packages.

Since 1990, the Australian Mineral Systems project of the Australian Geological Survey Organisation (AGSO) has created several metallogenic GIS packages: Coronation Hill Region (Wyborn *et al*, 1989; Wyborn, 1990a), Mount Isa (Jagodzinski *et al.*, 1993a, b, c), and Pine Creek (Wyborn *et al.*, 1994, Ratajkoski *et al.*, 1995a; Hazell *et al.*, 1995; Lewis *et al.*, 1995). The project has also undertaken digital map compilations including the industry funded digital data capture of some 28 1:100 000 geological maps of the Mount Isa region (Stirzaker *et al.*, 1993) and 15 1:250 000 geological maps of the Granites-Tanami area (Ratajkoski *et al.*, 1995b).

The prime reason for creating these packages was to carry out metallogenic analysis. However, in preparing these packages it became evident that the quality of the digital data, and hence, the ability to carry out effective metallogenic analysis, were closely controlled by how the data were captured, validated and integrated. With each project undertaken, it became increasingly obvious how some simple steps taken in preparing the base digital data sets could greatly enhance the

[1]For this paper we are using 'theme' as opposed to 'coverage' or 'layer', and the term 'attribute' to describe individual fields or items within each theme.

capacity of the GIS for metallogenic analysis. It also became apparent how these digital geoscientific data sets had applications in other scientific disciplines such as agriculture, anthropology and epidemiology.

In this paper, we wish to highlight issues and problems we have faced in creating these data sets and offer solutions (suggestions??), most of which highlight the need for, and the advantages of, uniform national standards. We will discuss the issues in three sections: digital map data, digital point databases, and data documentation and storage. Finally we will speculate on what opportunities geoscience GIS packages could offer us on a national scale.

2. ISSUES OF DIGITAL MAP DATA: PROBLEMS AND SOLUTIONS

2.1 Scale of field capture of data versus the 'scale' of the digital data that is utilised in the GIS.

> ***Problem:*** *Many digital 'maps' are simply digital compilations that have been created for printing paper maps at scales which are often far smaller than the scale at which the data are captured in the field.*

In pre-digital map production, the scale at which the final map was to be produced heavily influenced the amount of detail that was captured in the field. For example, if the final scale of map production was to be 1:250 000, the regional mapping tended to be more reconnaissance, rather than the more detailed mapping required for either 1:100 000 or 1:25 000 scale map production. At these 'traditional' map scales, most minor isolated outcrops were not portrayed on the map. The resultant geological maps represented a synthesis of all observations at a site, as it was impossible to portray all of the data collected in the field, particularly at 1:250 000 scale. Modern GIS systems however have the capacity to store all field observations and it is the ability to store this additional information that enhances the base geological map in the GIS.

Ideally, the digital version of the field data to be used in the GIS should be captured at the scale of the field photographs or topographic bases and ought to contain all detail collected in the field. Small polygons termed 'minimum polygons' should be drawn around isolated outcrops. This step is essential if any numeric analysis is to be undertaken of attribute data within polygons (*e.g.*, whole-rock geochemistry, magnetic susceptibility measurements, mineral deposits). If these small polygons are tagged as 'minimum polygons', they can be readily discarded if the printed map is prepared at a scale which is smaller than the scale at which the data are captured.

In pre-digital 1:100 000 geological map production, although field data were captured at the scale of the field photographs (say 1:25 000), most editing and revision was undertaken at the scale of map production (Fig. 1A). This map could then be further generalised to 1:250 000 for production at that scale (Fig. 1A). However, in order to meet the demands for precise analytical work within a GIS, it is becoming obvious that not only should the base geological map be compiled at the scale of the original field photographs (1:25 000), all editing and revision should also be done at that scale. This includes integration and validation against all other relevant data sets (including field point observations and geophysical survey data), to ensure locational accuracy of geological boundaries and faults. Once this has been done, the geological data can then be generalised to 1:100 000 or 1:250 000 scale and most GIS software has the capacity to undertake parts, if not most, of this process digitally (Fig. 1B). This generalised digital version of the data is then used to print the paper maps, but **is not to be** the base geological map for an analytical GIS. Conversely, the digital geological data compiled at 1:25 000 scale cannot be used to print maps at 1:100 000 and 1:250 000 scale. The only workable solution at the moment is that, to meet both the needs of printed map production and GIS analysis, there will have to be two or more versions of the digital geological map data from the same area (Fig. 1B).

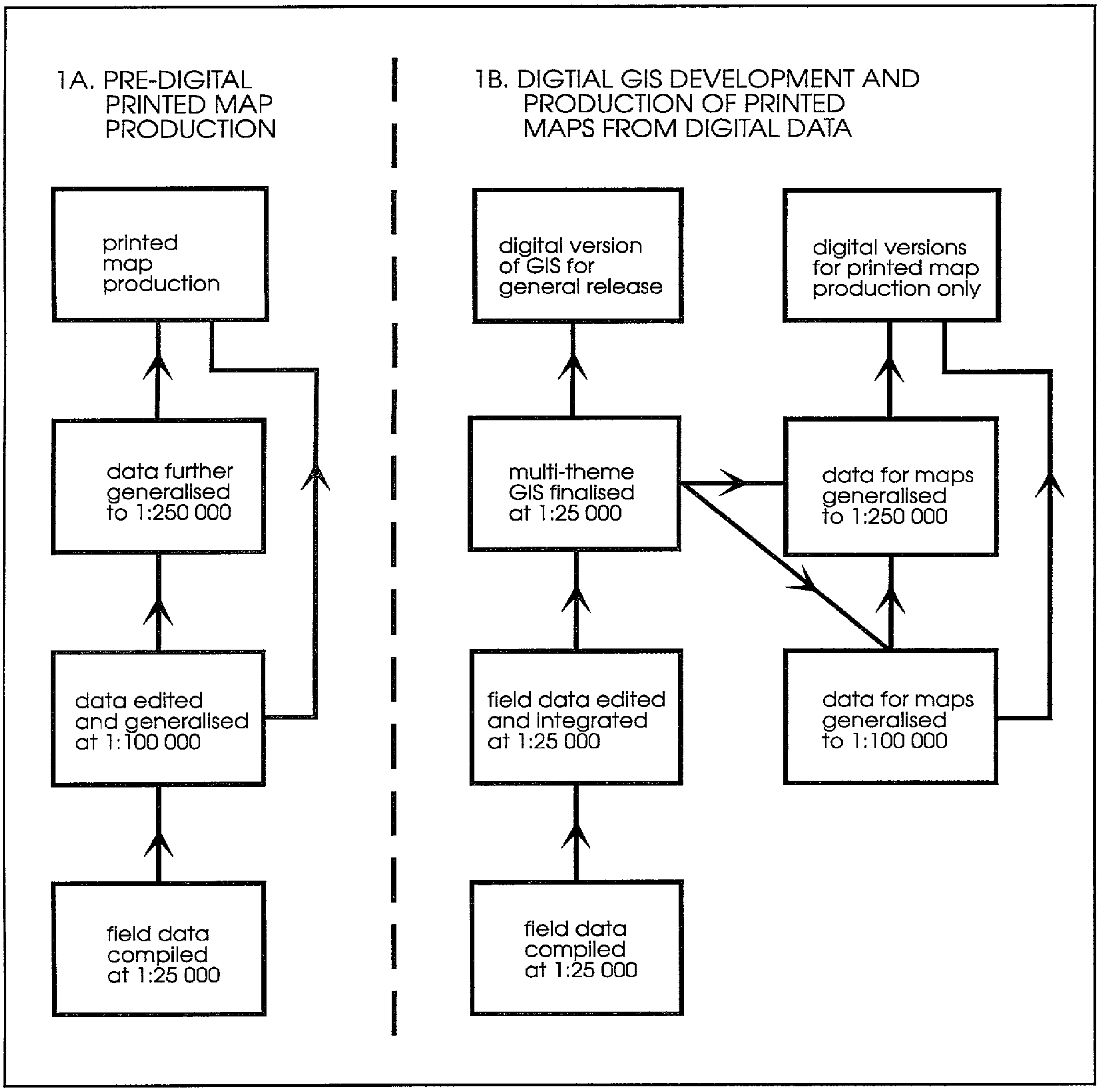

Figure 1. Comparative flow charts for preparing printed maps: 1A. Pre-digital printed map production. 1B. Digital map and GIS production.

Solution: *The digital base geological map used in a GIS ought to contain all data collected in the field and should be compiled at the scale of field photographs or topographic bases. It should also be validated against all other relevant data sets. The digital copy that will subsequently produce the printed map, can be synthesised from the GIS base map, and be a subset (generalisation) of those features that can be legibly portrayed at the scale of the printed map.*

2.2 Under-utilisation of GIS systems to capture data normally included in explanatory notes and map commentaries.

Problem: *Many of the digital geological maps available under-utilise the power of the GIS to capture attributes that were traditionally only referenced in accompanying map commentaries and explanatory notes.*

Modern GIS can almost create an 'intelligent' map by attaching attributes to both the lines representing the geological boundaries and linear features such as faults, as well as the individual geological polygons themselves.

For geological boundaries, the Tasmanian Geological Survey has developed an excellent system in which boundary types include not only the traditional position inferred, accurate or approximate classification, but boundaries are also tagged if they are gradational, sharp, unconformable, *etc.*, (Roach, 1994; 1995). In addition, using digital functions such as 'direction of arc'(that record the direction the arc was originally captured) it is possible to tag which side of the geological boundary is the younger or older unit. For faults, it is also possible to tag which side of the fault is up thrown or down thrown (Roach, 1994; 1995). Where a digital map is compiled from multiple sources, it is also possible to code each arc with its source.

For geological polygons, it is possible to attribute each polygon with information on parameters such as dominant lithology, dominant mineralogy, age, or if the polygon is a granite, which suite, granite type, whether it is fractionated, *etc.* In the Pine Creek and Mount Isa GIS packages this information was added by creating a relational table containing the additional thematic data for each stratigraphic unit listed in the map legend of the primary geological map (Wyborn *et al.*, 1994). This table could be integrated with any theme in which the same stratigraphic names occur (*e.g.*, solid geology).

Digital point databases can also capture much information that was previously lost to the purchaser of the map as it was locked away in field notebooks, or else summarised within accompanying reports. For example, many structural measurements could be taken at a site, but only the one considered to be most representative at the location was displayed on the map. All other observations can now be stored and prioritised so that once the scale of the final printed map is decided, only those observations that can be shown without overprinting are plotted.

For field capture of data to be used within a GIS, structured notebooks are essential (*e.g.*, Blewett, 1993). Traditional free hand notebooks encourage geologists to synthesise data at the outcrop stage and only record information that is required for the end purpose of the data (*e.g.*, a specialised scientific paper). Free hand field notes are often so cryptic that they can only be deciphered by the scientist who recorded the data. Structured digital notebooks with associated coding systems of attributes, encourage more systematic clean data collection (Withnall *et al.*, 1992). They can be utilised to make the geologist note a minimum number of **coded** observations to be taken at each site, ensuring that the GIS produced is not biased towards the specialty of the recording scientist. Coding is essential as it avoids spelling mistakes and assists in clean data entry. This in turn, helps guarantee that all data are retrievable, greatly enhancing the analytical power of the GIS.

Field photographs and sketches can also now become part of the GIS package, and be viewed relative to the base geological map. Any image or sketch can be scanned and stored against a point theme that identifies the associated location. Currently the only limitation to capturing photographs and sketches is the amount of storage space available for memory hungry graphics.

> ***Solution:*** *As much geoscientific information as possible should be captured and attributed within the digital GIS. All information collected in field notebooks should be entered, either in digital databases, as attributes attached to the relevant polygons, or as scanned images. It is preferable that digital 'notebooks' are used to encourage systematic data collection and eliminate errors in subsequent data entry.*

2.3 Lack of uniform coding systems for map units, particularly Cainozoic and other 'cover' units.

> ***Problem:*** *The ability to compile an infinite number of geological maps as a seamless theme on a national scale is limited by the lack of national uniform coding of stratigraphic units.*

In order to combine more than one geological map into a seamless theme, it is first necessary to standardise map symbols and to create a unique map legend for all geological units within the project area. The AGSO publication 'Symbols used on geological maps' (Anonymous, 1989) has become a *de facto* standard for digital geological map symbols. However, encoding the geological map unit names into a unique national system is not easy. Although several State Geological

Surveys have developed their own coding system for stratigraphic names, these apply only within their state.
The digital version of the Australian Register of Stratigraphic Names gives all stratigraphic units in Australia a unique coding on a national scale (Lenz *et al.*, *in prep.*). Its usage has declined of recent years as is evidenced by many names on published maps and in published papers that have not been formally registered. This has lead to a proliferation of informal stratigraphic names in the literature, many of which are duplicates of names already formally registered, sometimes within the same province. The aim of the Stratigraphic Names committee is to avoid such conflicts, and ensure that a unique coding can be assigned to all units Australia wide, thereby allowing the compilation of maps on a national scale as a seamless theme. Its usage could become more common if Australian journals, such as the Australian Journal of Earth Sciences or the AGSO Journal, insisted on only registered stratigraphic names being used in papers.

Traditionally, in poorly exposed areas or high grade metamorphic terrains, such as the Eastern Goldfields and the Arunta Block, formal stratigraphic names are rarely used, and map units are distinguished by letter codes such as 'Ag' or 'Pcf'. In these areas, developing a unique coding for all units on all maps covering the province is extremely difficult, particularly as the same letter codes are often used for different units within the same province. Projects working in these areas should attempt to use formal stratigraphic names, or else set up a unique coding system that does not have conflicts at least within a province, if not on a national scale.

Exceptions would probably have to be made for Quaternary or cover units that are rarely given stratigraphic names as they inevitably fail stratigraphic nomenclature rules. Uniquely coding these cover units in regional scale digital map compilations is further complicated in that the usage of terms such as laterite, colluvium, alluvium, *etc.* is rarely applied uniformly within a geological province, let alone at national scale. For example, in the Tanami digital maps project (Ratajkoski *et al.*, 1995b) the usage and coding of terms such as 'laterite' and 'alluvium' varied between adjacent map sheets. A solution was actually proposed by the Geological Survey of Queensland in 1983 (Grimes, 1983), who established an excellent standard of nomenclature not only for Quaternary and cover sediments, but also for their map abbreviations. This scheme has not as yet been adopted on a national scale.

> ***Solution:*** *All stratigraphic names appearing on published maps, data sets and publications should be registered with the Australian Register of Stratigraphic Names. The coding system proposed by Grimes (1983) for Cainozoic units should be adopted as a uniform national standard.*

2.4 Varying standards for capturing data only held on printed maps.

> ***Problem:*** *Many resources are being wasted in capturing existing maps using less than acceptable standards of digital data capture.*

With the increasing demand for digital map data, speed and cost reduction are predominating over the desire to capture the printed map as accurately as possible. Many so called 'quick and dirty' digital versions of printed maps are now recognised as being totally inadequate for high quality GIS analysis.

An accurate digital version of a base geological map is fundamental to the development of any geoscientific GIS. Data capture programs should work from the original colour separate, film reproduction material (repromat) used in preparing the final printed map. Although the base map can be either scanned or hand digitised, scanning gives a more accurate reproduction of the original map, particularly since new developments in scanning technology allows capturing of different line weights into different themes.

One method used to accelerate digital map production is to manually trace the geological boundaries, faults, lineaments, *etc.*, onto separate transparencies and then to scan each theme individually. For data quality, scanning of the original base map, although more time consuming, is definitely the preferred option. Digitising by hand or scanning hand traced transparencies both introduce the potential for human errors. In some digital data capture programs, during the tracing phase the data has also been simplified or degraded to facilitate capture. These deliberately degraded maps have no part in quality GIS packages.

Another source of error in digital data capture is the scanning or digitising of **paper** copies of the geological maps. Because paper copies distort over time, particularly in humid regions, digitising of a paper copy can introduce significant locational errors in the base map that cannot easily be mathematically rectified or 'rubber sheeted' back to match correct geographic coordinates. For example, a paper copy of the Mount Isa 1:500 000 base map had stretched more than 1 cm in an east west direction when compared with the original printer's base, but the north-south distortion was not as pronounced.

> ***Solution:*** *Where possible, digital capture of old printed maps should utilise scanning techniques on original film repromats. As digital capture of the original repromat printers' bases needs only to be done once, organisations should combine resources to ensure that the best possible digital version of the original map is created.*

2.5 Capturing old maps in which features have been modified to enhance cartographic presentation.

> ***Problem:*** *Existing printed maps have features that have been generalised or modified, or only portray representative features to enhance cartographic presentation.*

Particularly with the 1:250 000 scale maps, and especially where the geology is very complex and detailed, only representative geological features are usually included in the final printed map. For example, in an area of tight folding, not all anticline axes will be included, only representative ones. Traditional geological map production often relied on the user making a visual interpretation of the data to determine where features such as anticline and syncline axes occurred. Most commonly only a few representative axes were drawn, the remainder were interpreted visually by the user from fold 'shapes' and the position of associated dip symbols. Although it is possible to write complex algorithms to detect the location of anticlines axes, it is far simpler if they are each drawn individually. For more effective metallogenic analysis, all anticline and syncline axes need to be identified, not just representative ones (this point also applies to mappers capturing field data digitally).

Another problem is that in traditional cartography, important features such as faults and geological boundaries were broken so as to be able to insert either a geological or geographical name or symbol. For example in an analysis of the Pine Creek GIS, the Woodcutters Pb-Zn-Ag deposit, which is located right on an anticline axis (Fleming *et al.*, 1994), was not selected in a search for all Pb-Zn-Ag deposits that are adjacent to anticline axes. This was because in the original base map, the anticline axis had been broken to insert the name 'Woodcutters' at the precise location of the mine. If the map is to be used in metallogenic analysis, where features such as faults, geological boundaries, *etc.*, have been broken to insert labels, they must be rejoined. (Note: this issue reinforces the argument that the GIS package should be developed first and the digital cartographic representation be developed later.)

> ***Solution:*** *If the original source is a published paper map, consideration needs to be given to adding all metallogenically important features (e.g., anticlines, synclines) and joining up arcs that have been broken to accommodate geological and geographical labels.*

2.6 Duplicate arcs and automatic cleaning facilities.

> ***Problem:*** *Where the same arc is in several themes, it does not have the same geographic coordinates.*

When creating multi-theme GIS packages ensuring that arcs duplicated in different themes have the same geographic coordinates is not easy. One example is faults that can be in both the faults theme, and as geological boundaries in the geological polygon theme; another is where specific geological boundaries such as unconformities are also boundaries between different metamorphic facies. Unless care is taken in the preparation of the individual themes with duplicate arcs, then when they are combined, many spurious arc intersections and sliver polygons can result (Fig. 2D, 2F), preventing effective modelling and data analysis.

Where derivative themes are developed from primary polygon themes, (*e.g.*, creating a solid geology theme from a geological outcrop theme) it is essential that boundaries common to both themes are copied from the primary theme into the derivative one, rather than being redigitised or drawn freehand. Once the same arcs occur in two or more separate polygon themes, automatic editing facilities (such as 'clean' in Arc/Info) must be used with extreme care, with fuzzy tolerances set to an absolute minimum. Alternatively (and the preferred method by the authors) is that all themes that have identical arcs within them must be manually edited. With manual editing, all changes made to an arc in one theme, must be replicated on duplicate arcs in other themes. If due care is not taken with both manual and automatic editing, the derivative themes can never be accurately merged together, particularly with the original primary data theme (see Figs 2D, 2F).

> ***Solution:*** *To ensure effective modelling and analysis on multiple themes, all identical arcs must be copied into derivative themes. Automatic editing facilities must not be used and any manual editing must be replicated on duplicate arcs in other themes.*

2.7 Portrayal of faults.

> ***Problem:*** *The way faults are captured and stored within a GIS can make metallogenic analysis of deposits adjacent to faults difficult, if not impossible.*

How faults and geological boundaries are stored in a multi-theme GIS heavily influences the ability to undertake effective metallogenic analysis for fault-related deposits (Fig. 2). There appears to be no standard way of either capturing or storing faults in GIS[2]. In a traditional paper map, the faults and the polygons are naturally together on the one layer. However, with digital data, if the faults and the boundaries of the geological polygons are stored in the one theme, then the extensions of the faults outside of the polygon boundaries will all become 'dangle errors' (Fig. 2B) complicating editing of the polygon theme. This has lead to the common practice in digital data sets of storing the geological boundaries as polygons on one theme, and the faults as linear features in an arc theme. How they are captured and then stored on these two themes is variable.

In many available digital maps the faults were originally digitised separately from the relevant geological boundaries and the results are shown in Fig. 2A. For maps prepared in this way, it is impossible to get the faults and the geological boundaries that are also faults to have identical geographical coordinates, no matter how much care is taken in digitising. This problem often goes unnoticed, as when the data are printed out at the scale of the map to be published, say 1:100 000, this error is not apparent. Only when the data are printed out at a larger scale, say 1:25 000, or used in analysis, does it become obvious that the faults and the associated geological boundaries are not coincident.
If the faults and geological polygon boundaries are to be shown on separate themes, then duplicate arcs must be digitised only once and copied into the relevant themes. There are two methods of

[2]In this and following sections, the discussion is based on Arc/Info terminology. Many of the situations described are equally applicable in other GIS software, although the terminology may be different.

storing the faults and the geological boundaries. In Fig. 2C the total fault is in the faults theme, and only that part of the fault that forms a boundary between two differing geological units is in the geological polygon theme. If during analysis of the polygon theme, a search is made for all areas of Unit 1 that are in contact with the fault, then the area where the fault is entirely within Unit 1 will not be selected. Furthermore, if the faults are intersected back into the polygon theme, the additional polygons created by this 'splitting' may have to be labelled (Fig. 2E).

In Fig. 2D another alternative has been shown. Here, the total fault is in the faults theme, and where the fault splits a polygon, it still remains in the polygon theme. For analysis purposes this methodology has a distinct advantage as it breaks up the polygons into the smallest geologically meaningful units, for more detailed metallogenic analysis. However, this method does not show the extension of the faults into Unit 2, and a search of the polygon theme for all areas in Unit 2 that are in contact with a fault would not select these areas.

As is shown in Fig. 2E, it is possible to intersect the faults theme back into the geological polygon theme; provided any editing of the duplicated arc in one theme is exactly replicated in the other theme. If care is not taken in editing, errors such as sliver polygons may result when the themes are intersected (Fig. 2F), and faults still may not intersect polygons of interest.

Methodologies shown in Figs. 2B, 2C, and 2D all have advantages, but for GIS packages where fault related analyses are to be undertaken, 2B is definitely the preferred option. No matter how much care is taken, whilst duplicate arcs remain in separate themes it is impossible to guarantee that any editing on one arc in one theme will be replicated on the duplicate arc in the other. Regardless of which method is used, for quality GIS analysis it is essential that if an arc in a geological theme represents both a fault **and** a geological boundary between two different units, **it must be tagged as both.**

One common analysis of faults within geoscience GIS is to determine their total length to help identify major fault systems. However, most GIS only measure the length of a linear feature between nodes. In 2B, if an attempt is made to select all faults longer than a certain length, the fault will have nodes where the polygon boundaries intersect, the total fault length cannot be easily determined. In 2C and 2F, where the faults are in a separate theme, the faults can be 'unsplit' to remove the intermediate nodes, and the total length determined. (In Fig. 2B, if the faults are properly tagged it is possible to select them and move them to another theme, and remove the intermediate nodes so that their total length can be calculated).

However, there are at least two major disadvantage of 'unsplitting' the arcs that represent the faults. Firstly, it will be more difficult to classify them according to their orientation, unless the faults are linear and have no significant changes in direction. This is because routines that calculate the orientation of arcs, often calculate the angle between nodes (Fig. 3A). If the intermediate nodes are removed and there is significant change in direction along the fault (*e.g.*, arcuate faults), then the calculated orientation will not represent the orientation of sections of the fault (Fig. 3B). This is crucial in metallogenic analysis, as orientation of faults is often a key ingredient in the development of some ore deposits, particularly those that are structurally controlled. Secondly, 'unsplitting' the arc can cause a reversal in the function 'arc direction' (G. Young, Mines and Energy of South Australia (MESA), *personal communication, 1995).* If 'arc direction' has been used to attach attributes that apply only to one side of the fault (*e.g.*, thrust fault symbols, which side of the fault is down thrown, *etc.,)* this reversal may result in these attributes being spatially incorrect.

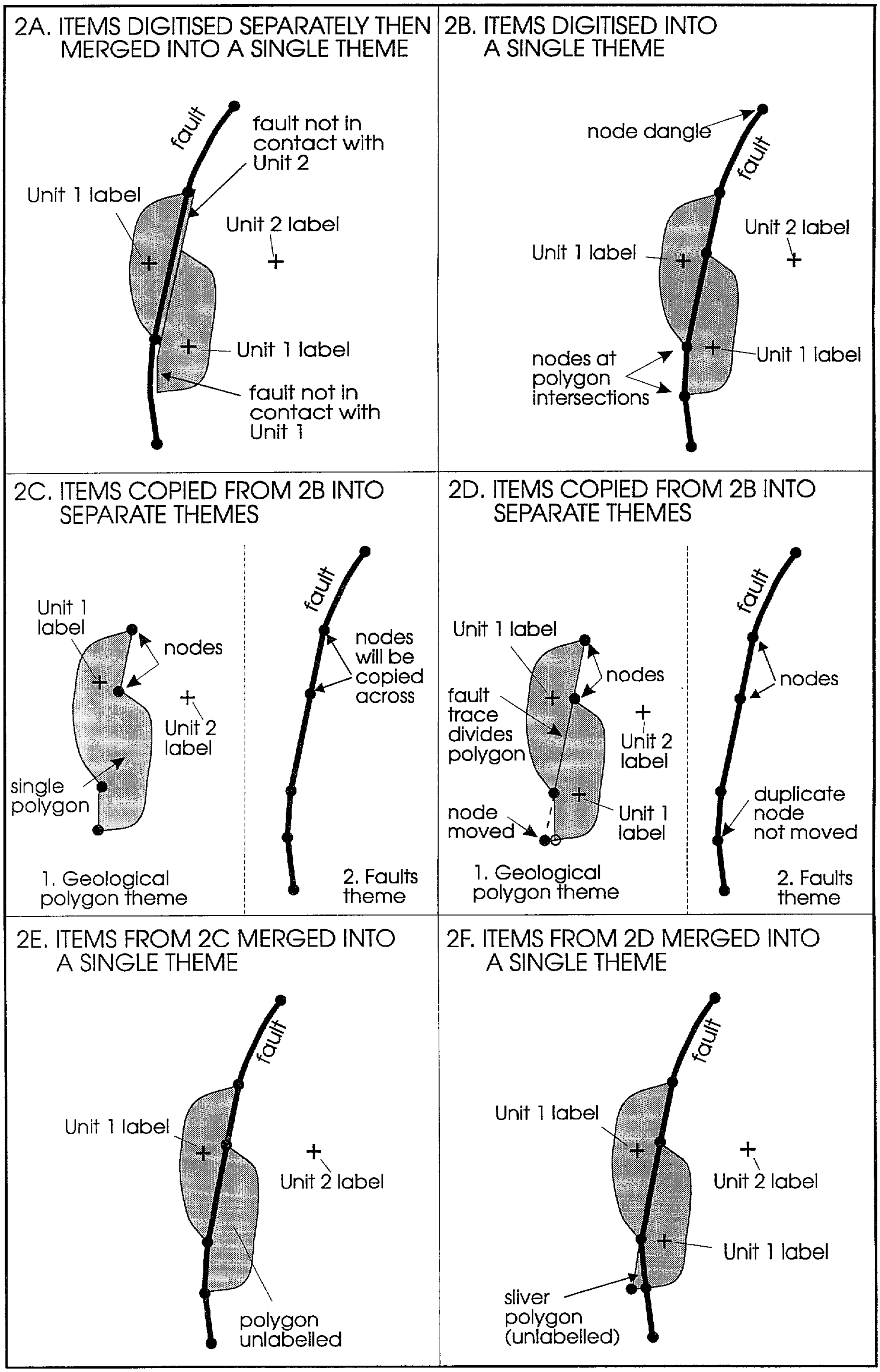

Figure 2. Ways of portraying faults and geological boundaries in a GIS.

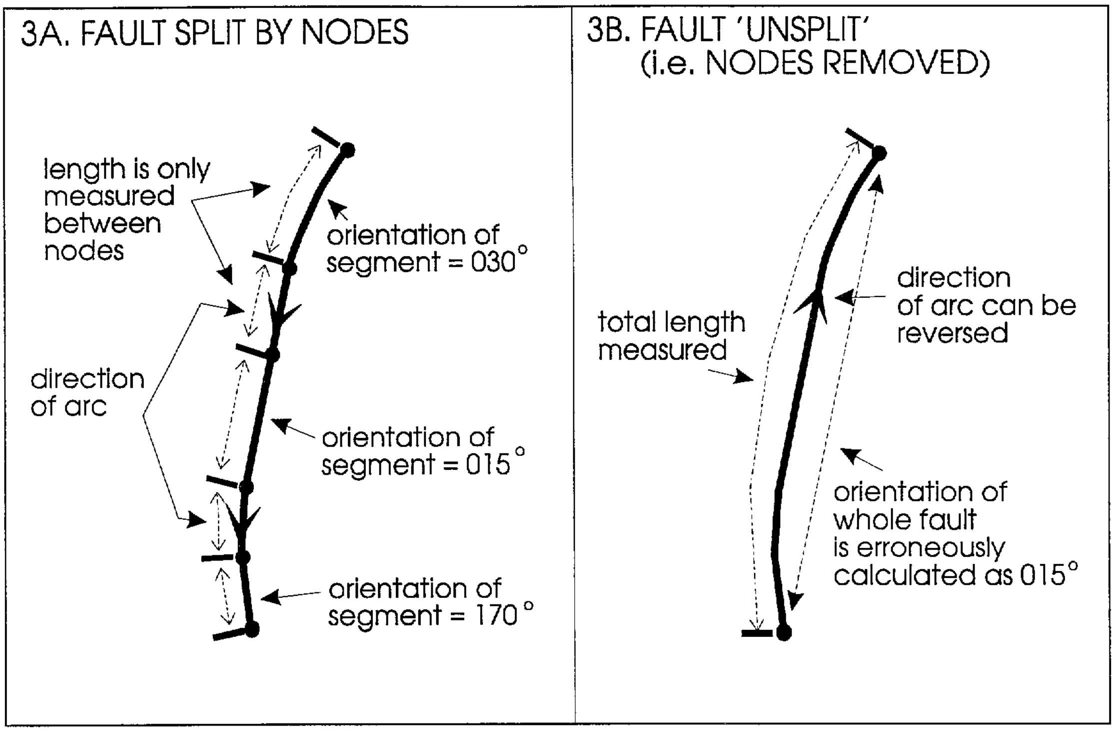

Figure 3. The effects of removing nodes from arcs that represent faults.

For this reason, it is best that the arcs representing the faults are not 'unsplit', and that a group of arcs that represent a particular fault have a common attribute that uniquely identifies that fault. One option that is available in most GIS software is the ability to define related linear features such as bus routes, telephone lines, water and sewage services, *etc.* as 'routes'. 'Routes' readily allow all arcs that represent a fault to be grouped together so that the total length of the composite arcs representing the fault can be determined.

The way faults are captured relative to their associated geological polygons and stored in metallogenic GIS packages should relate to the type of analysis to be performed on the data set. However, for public domain data sets a standard and systematic methodology should be developed and accepted. In digital data sets where faults are captured using methodologies illustrated in Figures 2A and 2C, it is virtually impossible to carry out metallogenic analysis for fault-related deposits. Unfortunately these are the most common methods used.

> ***Solutions:*** *All faults should be captured and stored as part of the geological polygon theme. If a boundary is both a fault and a geological boundary it should be tagged as such. All arcs belonging to a single fault should be grouped together using 'routes'. If there are nodes at significant changes in orientation, these should not be removed.*

2.8 Depiction of dykes and veins.

> ***Problem:*** *Most dykes and faults are actually narrow linear polygons and although they have finite width on the ground they are represented as linear features on most maps and in GIS.*

Features such as dykes, veins and fault zones are represented on geological maps and in digital data sets as lines. In analysing point data within associated polygons, there are advantages in having veins, dykes and faults portrayed as linear polygons of finite width. For example, dolerite dykes have distinctive geochemistry, and if the dykes are represented as lines, they will have to be eliminated from an analysis that averages all geochemical points within a polygon (Wyborn *et al.*, 1994). Dolerite dykes also have distinctive magnetic susceptibilities and if the dykes are shown as polygons, these values can be averaged within the polygons and the resulting map compared with magnetic images or interpretations of magnetic data.

In mineral deposit analysis, a disproportionate number of mineral deposits occur on faults. Depending on the scale, it is often difficult to get the point representing the mineral deposit to plot on the correct side of the fault. If the fault is a linear polygon then the point can be positioned within the fault zone. Provided the width of the faults, dykes or veins has been recorded, it is easy to convert these linear features into polygons by one of two methods: i) create a parallel arc according to the width of the feature or ii) buffer the linear feature according to the recorded width. Changes in width of the linear features can be recorded if the arcs are split by nodes at these points.

> ***Solution:*** *Veins, dykes and faults can be drawn as narrow linear polygons or as buffers. If the dyke, vein or fault is depicted as a line then its width should be attached as an attribute.*

3. ISSUES OF DIGITAL POINT DATABASES : PROBLEMS AND SOLUTIONS

3.1 Poor quality of location information.

> ***Problem:*** *Many data sets collected have very poor locational information*

Where data are obtained from scientific papers in international journals, open file reports and other old data sources, accurate locations of the data samples are often hard to obtain. In many scientific journals, the emphasis is on how the data are manipulated and interpreted, not on where the data points came from. Many Ph.D. theses do not have accurate sample locations listed. Many major databases only store locations in latitude and longitude in degrees and minutes and do not have the capacity to store the data in seconds. The preferred option is that the locations should be stored to the greatest degree of precision (*e.g.* latitude and longitude in degrees, minutes and seconds or full Australian Metric Grid (AMG) coordinates with 6 digits for the easting and 7 digits for the northing).

Even where reasonably accurate locations are available, storing just the locational coordinates is no longer sufficient. Databases should also store method of recording location and accuracy (Ryburn *et al.,* 1993). If Global Positioning Systems (GPS) have been used to determine the location, the datum used **must** also be noted. If these steps are followed then, firstly, data with poor locational accuracy can be discarded in more detailed analysis and, secondly, where the method of location is recorded it is possible to determine if the site has absolute or relative accuracy (see section 4.3).

> ***Solution:*** *The database must have the capacity to store location information to the greatest degree of precision and at all times the precision used to store the data locations should be sufficient to handle the most accurate data in the set. The method of recording location and accuracy must also be stored.*

3.2 Geographical coordinate systems in which the point data are stored

> ***Problem:*** *Many databases store locations in such a way that it is difficult to translate into other coordinate systems.*

One advantage of most GIS packages is that they readily allow projection to other coordinate systems. However, much of the locational information stored in databases for sample locations does not readily allow this. For example, many databases only store 6 digit AMG coordinates, without recording the AMG zone or the relevant 1:100 000 map sheet. These locations are not easily translatable into latitude and longitude coordinates.

In any database, locations should be stored in both full AMG coordinates and in latitude and longitude. The advantages of data stored in both systems is that data can be easily extracted as AMG coordinates for use in projects that only cover 1:100 000 or 1:250 000. The same data can also be extracted in decimal degrees of longitude and latitude for incorporation into province-wide data sets which extend over one or more Zone boundaries, or projected into another Cartesian system (*e.g.*, Lambert Conformal, Equidistant Conic, *etc.*) for regional or continent-wide analysis. Where data are stored in two systems, the original observation should be tagged. (In the AGSO OZROX field geology databases, by storing in both coordinate systems, as data are entered, a check is made to ensure that the data point also plots on the specified map sheet. If it does not fit, the site is rejected).

> ***Solutions:*** *It is preferable that whatever coordinate system is used to store the data, it can be readily translated into other coordinate systems. If AMG coordinates are used for field locations, it is essential that the Zone number or map sheet number (1:250 000 or 1:100 000) and the full coordinates (6 figures for the easting and 7 for the northing) are stored to facilitate translation into decimal degrees of longitude and latitude. The original coordinate system that the data were collected in should also be recorded.*

3.3 The location of sites: relative accuracy versus absolute accuracy.

> ***Problem:*** *Site locations determined using GPS have only absolute, not relative accuracy.*

With the widespread acceptance of GPS for navigation in the field and obtaining site locations, another source of error has crept into digital maps and data sets built from such point data (*e.g.*, geological maps, stream sediment survey data). There are at least two possible sources of locational error with GPS readings:

> i) at best, unless differential GPS readings are taken (*e.g.*, Holloway, 1995), most GPS systems can only give accuracy to 100m, and depending on conditions, may be as inaccurate as 600m.
>
> ii) Currently in Australia there are at least 4 different datums used - Australian Geodetic Datum (AGD) 66, AGD 84, World Geodetic System (WGS) 84 and the Geocentric Datum of Australia (GDA). Unless the GPS is set to the same datum as the base map the error can be as large as 300m (for example between WGS 84 and AGD 66). With the hopeful standardisation to the GDA coordinate system by the year 2000 (Steed, 1995), the datum on which the GPS is set should not be an issue.

It also is important to remember that GPS sites provide absolute, but not necessarily relative accuracy to geographic features. In traditional geological mapping, most sample points were located on air photographs, the sample points were transferred to a registered map base, and then the AMG coordinates of the samples determined. Assuming the geologist knew where he (she) was, this method automatically gave a point location that was accurate relative to a feature on the base map, such as the intersection of two streams or a geological boundary (Fig. 4). As locations derived by GPS readings only give absolute accuracy, then when they are incorporated into a GIS, they may not have relative accuracy to geographic or geological features on the registered map base being used for compilation. For example, in Fig. 4, a sample of Unit 2 has been taken from the junction of two streams. If the sample point is plotted relative to the junction of the two streams, then it plots in the correct geological unit. However, if the GPS location is used, and an allowance is made for the locational accuracy (taken in this case as 200m), then although the sample has absolute accuracy, it does not plot in the correct geological polygon. If the geological boundary was moved to incorporate this point, then the boundary would not have locational accuracy relative to the geographical features on the base map.

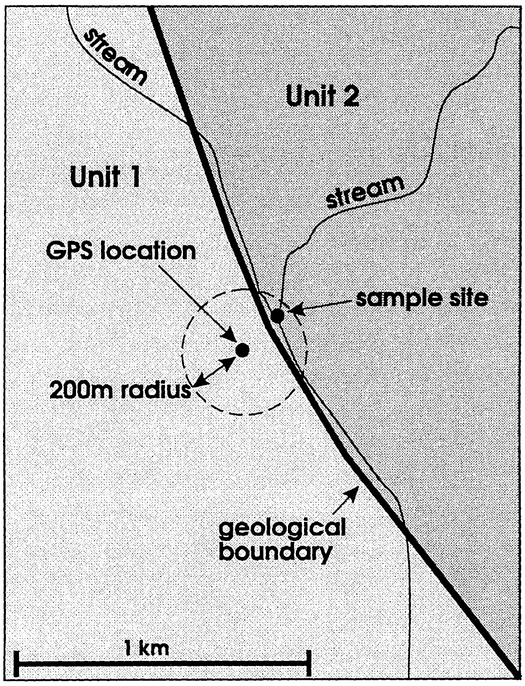

Figure 4. **A** GPS site that does not have accuracy relative to known geographic and geological features.

Consequently in building a GIS that integrates point and polygon information (*e.g.,* a geological map!) it is critical, before moving polygon boundaries in a GIS to fit a set of point data, that the method by which the sample location was determined be known. For projects such as geological maps and stream sediment surveys, it is usually the relative point location that should take precedence over the GPS reading. One option is to digitise and then store the relative observation location within the GIS, but also store the original GPS location within the primary database (N. Sandercock, (MESA) personal communication, 1995).

Giving the relative location precedence over the GPS assumes that the base map is the more accurate: this may not always be the case. While most populated areas have excellent 1:50 000 or 1:25 000 base control, many of the outback areas of Australia have very poor 1:250 000 topographic coverage with errors of hundreds of metres in drainage or roads (*e.g.,* Eastern Goldfields of Western Australia). In these areas the GPS will have the better accuracy. Therefore, before deciding which site is the most appropriate, the lack of relative accuracy of the GPS should be weighed against the lack of absolute accuracy in the 'registered' topographic base maps used for compiling the data.

> ***Solution:*** *Depending on the type of accuracy required for the point data, two methods of recordings of location may be required at most sites. The first method is a GPS reading which gives absolute accuracy. If the locations are to be integrated into a map, then the GPS must also be set to the same datum as the registered map base. For those sites where relative accuracy is important, it is preferable to locate the point on an aerial photograph, plot the location on the geographically registered map base, digitise and then store its relative location. At a bare minimum, the position of the site relative to the geographically registered base map (e.g., 4m east of creek, or 200m N of bore) should be documented. Differential GPS readings should be used wherever possible as they will give far greater accuracy than single GPS readings.*

3.4 Integration of point and polygon data.

***Problem:** Many point databases do not integrate with digital maps of the same area, even where these digital maps have been compiled from data that are stored within the point databases.*

To enhance analytical capacity, where relevant, every point must fit into its associated polygon, as mentioned in Section 3.1 on 'minimum polygons'. However in many cases, field observations are compiled into digital point databases and the digital maps are drawn independently. Rarely are the two data sets rigorously compared. GIS readily offers the capacity to relate the two types of data and ensure that most points can fit into the correct polygon. In the production of GIS packages, as soon as the polygon themes are complete the relevant points should be checked against the polygon theme. This methodology also acts as both a checking mechanism to verify the position of geological boundaries, and to also ensure that polygons are correctly labelled. It also acts as a validation process for data stored in the point databases, particularly where the data were entered by hand, and hence liable to typographic errors.

However, there are at least two valid reasons as to why points may not fit into the correct polygon:

i) Samples from points of relatively minor units that are not portrayed on the map (*e.g.*, samples of xenoliths, or narrow dykes and veins). To readily distinguish these points, an attribute called 'MODE' was added to the AGSO OZROX field geology databases. This attribute enables tagging of each sample point to indicate if it is representative of the dominant rock type of the polygon or whether it came from a rock unit of minor occurrence such as a vein or a dyke.

ii) Samples from locations which do not have relative accuracy (usually those collected by GPS - see Section 3.3).

***Solution:** When creating a digital polygon theme all point data should be integrated with the associated polygon data as soon as is possible, particularly when that point data have been used to create the polygon theme (e.g., field site descriptions and the subsequently derived geological map).*

3.5 Lack of data structure in databases.

***Problems:** Many databases store information that cannot be retrieved either because of poor data structures, lack of authority tables, or databases that are so complex that simple retrieval of data is virtually impossible.*

To develop an effective GIS, relational databases (*e.g.*, ORACLE, PARADOX, SYBASE) are essential. Attributes that contain free text must be kept to a minimum. Free text inevitably leads to spelling mistakes, and if the descriptions are very long they are difficult to effectively search through to select individual items. Databases need to be well structured with each attribute in a database only storing one fact, which in turn, requires only a few words to fill in, or preferably has an associated authority table. Authority tables facilitate standardisation, avoid spelling mistakes and allow for the case sensitivity of most database systems. However, the use of authority tables can in turn, result in complex data structures, with multiple one-to-many relationships, that make extraction of the relevant data very difficult.

***Solutions:** Relational databases to be used in GIS must be designed with the end use in mind, and must contain information that is relevant and easily retrieved. Authority tables are essential for most attributes and any free text descriptions should be kept to a minimum.*

3.6 Proliferation of coding systems

> ***Problem**: Multiple coding systems have been developed that are not readily translated between databases.*

With increasing acceptance that authority tables are essential, there is now a proliferation of geoscientific coding systems and no recognised standards. Although translators can be written, in many cases it is not a direct one-to-one translation. For example, for igneous rocks, the AGSO LITHNAMES authority table has over 200 codes whilst other databases only have 20. It is therefore not a simple transition of say GRT (granite) from the AGSO database into the GRNT (granite) code of a second database, as the definition of what is represented by the word 'granite' differs in both databases. In the AGSO 'granite' is restricted to rocks that have certain percentages of quartz, K-feldspar and plagioclase, whilst in the other data sets the use of the word 'granite' implies the whole family of rocks ranging from tonalite, through granodiorite to monzogranite and alkali-feldspar granite. This problem is exacerbated by the fact that many databases and their associated coding systems are poorly documented, and the actual definitions and derivations of the CODES used are unknown (see Section 4).

> ***Solution** Some standardisation of coding systems is essential. Where this is not available, full documentation is required as to what each of the abbreviations represents.*

3.7 The vast amount of valuable geoscientific information that resides on data cards, in hard copy reports, and on inaccessible PCs.

> ***Problem**: So much geoscientific data are either not yet digital and hence inaccessible to GIS or, if it is digital, is inaccessible or not properly archived.*

Despite the best efforts and intentions, there is still a vast amount of valuable geoscientific data in Commonwealth, State and Territory Geological Surveys to be captured digitally. The Surveys are now all making rapid progress in capturing old analog data including digital maps (*e.g.*, Roach, 1995; Baisden, 1995; Lewis and Suppell, 1995; Parker, 1992). However, there are still valuable data sets that are not digital, including the definition cards of the Australian Register of Stratigraphic Names and many petrographic sample descriptions. One frustrating aspect of the Mount Isa package was the 4000 position located descriptions residing unusable on thin section cards; for Pine Creek there were 6000. If this data were digital then it would have been relatively easy to accurately draw a metamorphic facies maps of both areas, or more importantly, locate areas that have metallogenically relevant alteration patterns (*e.g.*, presence of sericite, magnetite, alunite).

Open file company reports in State and Territory Mines Departments store vast amounts of highly relevant data very little of which is available in digital format. Although there are attempts being made to capture this vast data source (*e.g.*, Beams, 1995), more effort should be made now to have new open file data submitted in a digital format.

Although the Commonwealth, State and Territory Geological Surveys are rapidly developing major digital data sets, the vast majority of geology departments within Australian universities do not have a central system for storing digital data, particularly data collected under publicly funded programs such as ARC grants and Commonwealth post-graduate awards. Data is predominantly kept on the PCs of the individual scientists, and is not readily available to other scientists, particularly those outside the university department. The method of archiving the data is poor, and backups if they are done, are usually on floppy disks, or else stored as hard copy within filing cabinets. As funding grants are completed, the digital copy of the data usually goes with the individual scientist who created the data.

Perhaps one reason why there is little emphasis on the development of digital databases within universities is because the reward system for academic promotion and funding grants is biased towards scientific papers produced by interpreting data. There is no reward for database compilation and management (Callahan and Johnson, 1995), and until this eventuates, much valuable digital geoscientific data will be lost.

Solution: *Emphasis needs to be put on the importance of data being properly georereferenced, stored and archived and made available in useable digital format (particularly in universities).*

4. ISSUES OF METADATA AND DATA STORAGE: PROBLEMS AND SOLUTIONS

4.1 Data dictionaries and metadata for digital map themes

Problem: *Many digital data sets are provided without adequate documentation.*

Many digital data sets available have little or no documentation. Theme and attribute names are often abbreviated or encoded and it is not easy to decipher what they stand for. The minimum documentation should describe which package the data were developed in (Arc/Info, MapInfo, *etc.*) and state whether the data are in single or double precision. The type of coordinates should also be listed (lat/longs, AMG, *etc.*). The derivation of each theme should be described and cover issues such as was it digitised or scanned, what was the source data (give a map reference noting the age of the map) and at what scale the data were captured. If the theme has been derived by combining multiple themes, each should be listed. Each attribute needs to be fully defined: if a classification is used in defining the attribute (*e.g.*, S- or I-type granites) then the source reference for that classification should also be included.

Solutions: *All digital data sets should be properly and fully documented.*

4.2 Data storage and archiving.

Problem: *There appears to be little effort into addressing where data should be stored and archived from organisations which do not have appropriate facilities.*

Many working groups are focussing on issues of data standards and data transfer, but few are focussing on where data should be stored and archived. Directories are being set up to indicate where data are held, such as @ngis and FINDAR, but there are no programs for storing valuable geoscience data from organisations that do not have adequate archiving facilities for digital data such as AMIRA and most university geology departments. Any book or pamphlet printed in Australia, no matter how small its distribution, is given an ISBN number and stored within the National Library of Australia. In contrast, we have no central repository for digital geoscience data from those organisations that do not have the facilities to properly archive and maintain digital data.

Solution: *There is a need for setting up systems to store digital data from those organisations that do not have the appropriate facilities.*

5. OPPORTUNITIES

If we can start to address some of the issues discussed in this paper, then GIS offers us the opportunities to readily compile geoscientific information on a national scale. The current limitations reflect the lack of standards of data capture, data transfer and data storage and the proliferation of databases each with their own individual coding system. If these issues can be resolved, then it will be much easier to create national geoscientific GIS packages incorporating data from all State and Territory Geological Surveys, and universities, as well as compiling data from mining companies that have been submitted to the relevant Surveys in an easily accessible digital format. Once we are able to integrate geoscientific data on a national scale, we will be able to effectively integrate our data with data from other disciplines such as agriculture, environment and human health, and have an opportunity to make a national contribution on issues such as land use.

GIS offers opportunities for data to be used for purposes other than that for which they were originally collected. The petrologically unusual high-U Malone Creek Granite that occurs in the vicinity of the Coronation Hill deposit east of Katherine, Northern Territory provides an example. Although geochemical data on this granite were collected for a specific petrogenetic study, the data have since been used for many other purposes. For example, on a local scale the high U values from this granite have metallogenic implications because of the nearby U deposits (Wyborn *et al.*, 1990). The data have been used in environmental geochemistry as they show that more U is being incorporated in the local stream sediment than is coming from the nearby U deposits (Cruickshank *et al.*, 1990). There are also anthropological implications in that the presence of high background U, in combination with the presence of heavy metals, may have an association with the sickness country (Wyborn and Needham, 1990). On a regional scale, this granite is part of a suite of high U granites within the Kakadu National Park (Wyborn, 1990b) and may be a contributor to world class U deposits developed in this region. Comparing the data on a national scale, the Malone Creek Granite has some of the highest U values found in granites in Australia. In summary, once the data are compiled digitally, it is easy to use it in local, regional and national compilations not only for geoscience issues but also for other disciplines.

6. CONCLUSIONS

GIS offers many opportunities to make geoscientific data more readily accessible and offers the capacity for the data to be used for purposes other than what the original collector of the data envisaged. However, geoscientific GIS will not advance easily unless we first get the basic standards properly established. Only after that is achieved will we develop good quality GIS packages that will work on a state and national scale. If we do this, GIS will offer opportunities for geoscientists to make valuable new insights not only in their own field but also other national issues such as environment, agricultural, mining and other land use issues.

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Predicting Radon Hazard in Australia using ASSESS

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Abstract: *Exposure to elevated indoor radon levels is thought to cause up to 10% of lung cancers internationally. Radon levels are primarily determined by geological factors such as the distribution of uranium in soils and rocks, soil depth and permeability and groundwater movement. Geographic Information System (GIS) techniques can be used to predict areas with high radon hazard potential. Existing geological, geochemical and geophysical data were combined using ASSESS, a risk assessment software package, to provide a preliminary assessment of areas with high radon potential at continental scale, and for a regional case study for the Collie region in Western Australia.*

Introduction

Radon (Rn) levels in buildings are of concern because of the link between exposure to high levels of radon gas and lung cancer. It is estimated that up to 10% of total lung cancers may be attributed to radon inhalation (Bodansky 1987), and radon is thought to contribute significantly to the incidence of other diseases such as myeloid leukemia. As a result, the World Health Organisation and many individual countries have set standards for indoor air. The Australian National Health and Medical Research Council (NHMRC) guidelines recommend that indoor radon levels should be kept below 200 Bq m^{-3}.

It is important that Rn surveys be targeted to areas with the highest probability of elevated levels. Since radon distribution is controlled by a number of factors which vary spatially, prediction of radon hazard lends itself to the use of GIS technology. This paper assesses the use of geological data to predict areas with the potential for high indoor radon levels using GIS to combine different data types.

Table 1: Major factors controlling indoor radon levels, and relevant geoscience data sets

Factors controlling indoor radon levels	Available data sets	Data type
U content of rocks and soils	airborne gamma spectrometry	raster
	geochemical analyses	point
	lithological maps	polygon
Hydrological factors		
soil permeability	soil maps	polygon
faults and fractures	geological / geophysical maps	line
groundwater movement	hydrogeological maps	polygon / line
	bore data	point
Meteorological effects	(ephemeral)	
Building construction	(site dependent)	
ventilation		
building materials		

Factors affecting radon distribution

Prediction of radon hazard requires an understanding of the factors which control indoor Rn levels, which are reviewed elsewhere (Nero *et al* 1986; Gates and Gundersen 1992). Table 1 gives a list of the major factors affecting radon distribution and the types of relevant geoscience datasets which are available.

House construction factors (particularly the degree of ventilation) affect entry and retention of Rn in buildings, and seasonal and meteorological effects may be important. In general, however, these effects are minor compared to the effects of geology and soil permeability (Nero *et al* 1986).

Predicting indoor radon levels

A number of studies have attempted to predict radon hazard at regional to national scales using information on these controlling factors. At the simplest level, a single predictive factor is used. For example, Chadima (1989) prepared a generalised map of relative radon emission potential for South Dakota based only on lithology, and Rezvan *et al* (1988) used equivalent U concentration (eU) estimated from airborne gamma spectrometry (AGS) to predict indoor Rn for continental USA.

Existing studies indicate that eU from AGS is the single parameter which correlates best with indoor radon but it is not a good predictor, accounting for only about half the variation in radon from region to region (Revzan *et al* 1988). Jackson (1992) found a much better correlation between eU and the percentage of houses in a given area with Rn above a given level, so that eU can be used as an indicator of "radon hazard" rather than a direct predictor of Rn levels.

Other studies have combined data on a range of contributing factors. No explicit model exists for combining data layers, since the interaction of factors is complex and the relative contribution of each is not well established. As a result, existing studies have combined available data empirically. Assessments are made for regions which are defined on the basis of geology (geological province or unit) or on political boundaries (shire, county, state), requiring that the data be aggregated spatially. For example, Gundersen *et al* (1992) produced a map of geologic radon potential in the USA by empirically ranking each of five categories (geology, eU, soil moisture and permeability, indoor radon data and dominant building architecture) within 28 geologically coherent areas nationally and combining the scores to produce a "radon index" for each. Similar studies, combining information on a range of geological parameters to predict radon hazard, have been carried out for Sweden (Akerblom 1994) and France (Ministere de l'Environnement 1992).

Predicting radon hazard using ASSESS

In this study, Rn hazard was assessed at the national scale and for a regional case study for the Collie region in Western Australia. In each case, the best available data sets relating to U (Ra) content of rocks and soils, soil permeability and depth, presence of faults and groundwater depth and movement were collated. Soil moisture content was not considered in this study, as it changes so rapidly and there is no reliable method of estimating soil moisture over large areas. Meteorological effects were not considered, since they are ephemeral. Building construction factors are not relevant to regional assessments.

Data layers were analysed and combined using ASSESS, a risk assessment software package developed by the National Resource Information Centre (Bowyer and Veitch

1994, NRIC 1992). ASSESS produces an index of radon risk by allocating rankings to attributes of the factors controlling indoor radon levels. Each attribute is ranked from 1 (low impact) to 5 (high impact) and rankings are combined for the relevant factors. Since the index is additive, areas for which data is not available for a particular factor are assigned a rank of either 3 or 9. The former rank assumes average conditions and does not increase or decrease the risk, while the latter allows a spatial exclusion of areas with no data. ASSESS is designed to allow explicit examination of the effect of applying different weightings to the factors. These weightings range from 0 to 5 where 0 removes the factor from consideration, 1 includes the factor with equal importance relative to other factors, and weights 2,3,4 and 5 allow increasing relative importance of a factor.

ASSESS runs on ArcInfo GRID, and requires that data sets be in grid (raster) format. Gundersen *et al* (1992) and other previous studies divided the area of interest into regions based on either geological or political boundaries (state or county), and produced rankings for each region. This requires aggregation of data which may obscure important features. Because ASSESS uses a grid-based format, indices can be calculated for each grid cell, with the maximum resolution defined by the data set with lowest resolution. This approach maintains the maximum information content of the data, minimises subjective assessments of the data and allows each data layer to vary independently. In addition, it allows point data (such as occurrence of uranium deposits) and line features (such as faults) to be incorporated with the spatial data more satisfactorily.

National Assessment

The following data sets were used for the national study. All data were converted to raster format with 5x5 km grid cells:

- Estimated uranium content for mapped geological units, based on the Geology of Australia (1:2,500,000) compiled by BMR (1976) and average U concentration for various lithologies (Wedepohl 1969; Taylor and McLennan 1985; D. Wyborn, AGSO, *pers. comm.*) Since at this scale the geology was mapped as very broad lithostratigraphic units (Palfreyman 1984), such estimates are only indicative of the likely range for the dominant lithology. For example, Palaeozoic granites, coded 4 (4-8 ppm U), actually range from < 1 to > 10 ppm U.
- Major fault zones, from the Geology of Australia (1:2,500,000) compiled by BMR (1976).
- Location of mapped uranium deposits (AGSO unpublished data)
- Geochemical analyses from AGSO's ROCKCHEM database, which contains approximately 18,000 geochemical analyses for U. Grid cells were assigned a code on the basis of the maximum U content for analyses within the cell. Cells with no data were assigned code 3 (indeterminate).
- Relative soil permeability interpreted for the soil units of the Atlas of Australian Soils, Northcote (1972) (Simon Veitch, NRIC, unpublished data)
- Soil depth interpreted for the soil units of the Atlas of Australian Soils, Northcote (1972) (Simon Veitch, NRIC, unpublished data)

Airborne gamma spectrometry data were not included in the national assessment, as surveys are available for only about a third of the Australian continent.

Radon hazard was assessed in the context of population density reported by statistical local area (NRIC 1992 unpublished data, derived from the Australian Bureau of Statistics 1986 census), to determine areas where potentially high Rn levels are likely to affect a significant number of people. This method of reporting population data results in some anomalies where SLAs are large, but is generally reliable for the coastal areas where SLAs are reasonably small.

The results of the assessment, with all factors weighted equally, were presented as a national radon hazard map at a scale of 1:5,000,000. (The map is not presented here due to the difficulty of presenting it at small scales and in black and white, but copies can be obtained from the authors). It is important to remember that such an assessment is very sensitive to data quality, and is biased by sampling density. It can, however, be used as a broad indicator of areas where elevated Rn levels may occur in populated zones - for example, the Palaeozoic granite belts of eastern Australia.

Case study: Collie, WA

The Collie area in Western Australia was chosen as a case study to demonstrate the development of Rn hazard maps for a relatively data-poor area. The best available geological mapping is at 1:250,000 (not available in digital format), there is very little geochemical data and reconnaissance AGS only. Measurements by the Australian Radiation Laboratories and the Western Australian Department of Health (unpublished data) have shown some reasonably high Rn levels (up to 50 Bq m^{-3}), although still well below the NHMRC intervention level. The data sets used in the assessment were:

- Estimated average U content by geological unit. The geology was digitised in a simplified form from the 1:250,000 geological map sheet (SI 50-6, Wilde and Walker 1982). Uranium content for each unit was estimated using the limited published geochemical data for the sheet and for contiguous units in the surrounding areas, and by extrapolating from regional geology. The methods used are described in more detail elsewhere (Johnston, *in prep*).
- Fault zones. Major lineaments interpreted from airborne magnetics are available from the 1:250,000 scale compilation sheets for the Albany magnetic interpretation map (Alan Whitaker, AGSO, unpublished data).
- eU from AGS survey flown by the Bureau of Mineral Resources (now AGSO) at 1.5 km line spacing (grided to 500 m).
- Soil permeability and depth inferred from the Atlas of Australian Soils Sheet 5 (Northcote et al 1967) (Simon Veitch, NRIC, unpublished data).

The results of the analysis were presented as a radon hazard map for the Collie 1:250,000 sheet area (SI 50-6) at a scale of 1:1,000,000. Copies may be obtained from the authors The AGS data were considered to be the most reliable of these data sets, and were weighted more highly in assessing radon hazard. The main areas of high radon risk are associated with Cainozoic laterites developed over high U Archaean granites in the north and centre of the sheet area.

The results of two surveys of Rn in indoor air are available - 54 measurements in all on the Collie map sheet area. The surveys were carried out by the Australian Radiation Laboratories (S. Solomon, unpublished data) and the Western Australian Department of Health (L. Toussaint, unpublished data). Because survey data are not geolocated but are reported by postcode district (ARL) or township (WA Health Department), no direct comparison can be made with the radon hazard map for specific sites. It is apparent from the large range of indoor Rn values where multiple analyses are available that single analyses cannot be taken as representative for the reporting districts: for example, the six measurements in the Donnybrook area range from 9 to 49 Bq m^{-3}. All recorded measurements are less than 50 Bq m^{-3}, well below the NHMRC guideline, but it is important to note that no measurements have been made in zones of predicted high radon hazard.

There are a number of issues related to radon hazard which arise from geological studies in the area but are not apparent in the mapped data. For example, the Greenbushes pegmatites, which are mined for tin, tantalum and lithium, are characterised by high U contents, up to 20 ppm (Partington 1987). Since they are spatially restricted and intrude a sequence of low U gneisses and mafic to ultramafic metavolcanics and metasediments, they do not figure as high U on the maps. Current mining includes underground operations and it is possible that high Rn could accumulate in the mine, with potential occupational doses to miners. Similarly, although the Collie coal deposits are generally low in U, the average U content of coal ash from Collie deposit is 20 ppm and values up to 600 ppm have been recorded (Davy and Wilson 1989a). This is substantially higher than average soils and surface sediments, and potential release of Rn should be considered in disposal of fly ash from the Collie mine. It would not be appropriate, for example, to use the fly ash as an additive to cement.

Conclusions

A spatial information system such as ASSESS provides a useful framework for analysing radon hazard, since it allows data sets of various types to be used most effectively in the assessment. In particular, the use of a raster format maintains maximum spatial information content of the data and allows each data layer to vary independently.

The greatest weakness of the analysis is the lack of an explicit model to combine the data sets. It is not possible to develop such a model from current information, since the relative importance of factors affecting indoor Rn are so poorly understood, and there is very little information on interactions between different factors. It is important to remember that any combination of rankings assumes some weighting of the factors (usually equal weighting). By allowing the attribute rankings and factor weightings to vary in ASSESS it is possible to gain some appreciation of the sensitivity of the analysis to each factor, an important part of the analysis.

Predictions of Rn hazard can only be validated by comprehensive sampling of indoor Rn. Regional studies in the USA have compared measured indoor Rn levels in up to 25,000 dwellings with various factors to examine their reliability as predictors of Rn hazard. In most studies, however, the Rn measurements are aggregated for towns, regions or zip-code areas. It is obvious from studies such as that by Gates *et al* (1990), which distinguished bedrock units and shear zones as thin as 4 m in width using soil radon, that effects may be very localised and aggregation of data is likely to obscure relationships. Current sampling methods thus preclude appropriate validation of predictive studies. No clear assessment of the effectiveness of predictive methods can be made without properly geo-located Rn measurements for comparison.

The Collie case study demonstrates the type of regional map of radon hazard which can be produced as the basis for planning regional surveys. Such maps can only be validated by comprehensive sampling and analysis of indoor Rn. In the Australian context, where the risk of elevated Rn levels is generally low, such a sampling program may not be justified. Such maps must be used in conjunction with other information about the region, since some areas of potential hazard may not be identified by this type of analysis (for example, high U contents in coal fly ash).

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GIS Database of Murray Basin Hydrogeology

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Abstract: Salinisation of land and surface water is seriously degrading the natural environment and sustainability of agriculture in the Murray Basin. These problems are groundwater related, so a 1:250 000 scale hydrogeological mapping program was initiated between State water agencies and the Australian Geological Survey Organisation (AGSO). The 26 mapsheets were completed in 1994 and contain information on depth to water table, tops of regional aquifers, salinity, water levels and sustainable aquifer yield. AGSO is preparing a digital database from the mapping, using Arc/Info. Over 400 GIS coverages have been created from the Intergraph IGDS files used in map production. Themes from each mapsheet are appended to create seamless basin-wide datasets. To assist in the conversion process, AML-based tools were developed and integrated into a modified version of ArcTools. The interface also includes tools to help validate datasets and assist in compiling metadata. Compilation of the GIS product has greatly enhanced the utility of the hydrogeological information. Customised basin-wide maps of themes such as salinity hazard, potable and stock water supplies have since been generated. The introduction of GIS technology into this map series has dramatically changed how future mapping programs will be planned and implemented.

Introduction

The Murray-Darling Basin is the strategic water catchment for Australia, accounting for 75% of the nation's irrigated lands, a quarter of its cattle and dairy farms and half of its sheep, lamb and crop production. The region contributes over a third, or about $10,000m of Australia's natural resource-based production. However, degradation of land and surface water is seriously threatening the sustainability of this agricultural output. Annual production losses due to waterlogging and salinisation induced by watertable rise have been estimated at $220m (in 1988). The degradation to the natural environment remains unquantified.

Salinisation and water logging is a groundwater related problem, hence management strategies require an understanding of basin hydrogeology. To this end, the 1:250 000 scale Murray Basin Hydrogeological Map Series was initiated in 1987. The mapping, completed in 1994, was a collaborative effort between the water agencies of Victoria, New South Wales and South Australia and the Australian Geological Survey Organisation (AGSO). The objectives of the mapping were to show the influence of groundwater on salinisation, highlight present and potential salinity hazard, delineate useable groundwater resources and enhance community awareness of prevailing groundwater systems (Evans, 1992). The 26 mapsheets contain information on the depth to watertable, structural tops to regional aquifers, groundwater salinities, aquifer yields and standing water levels. Work commenced in 1994 by AGSO to prepare a digital database from the mapping. This involves creating Arc/Info coverages from the Microstation design files which underpin map publication.

The Conversion Process

The construction of an Arc/Info coverage from a source Intergraph Microstation design (IGDS) file is a multi-step process (refer Table 1). Aspects of this processing are discussed at length in many ESRI publications and by other authors (eg. Musto, 1990). Firstly, the source files need to be dearchived and prepared for reformatting into Arc/Info GIS coverages. A number of routine checks at this initial stage can minimise potential problems during conversion (Brodie & Tucker, 1992):

1) Information about the original data, such as bibliographic references, source, publication date and currency, scale and accuracy, map projection parameters and media type should be collated.

2) Details of any cartographic processes such as generalisation, reprojection or rescaling should also be recorded. The design files that are used should have gone through the polygonising stage of the cartographic process. This ensures that all polygons are closed, effectively reducing editing and cleaning of the GIS coverage.

3) Commonly, maps are rotated to fit orthogonal to the map sheet. This requires the mapping to be rotated back to a position appropriate for the projection used. Ideally, the coordinate system of the design plane in which the map is digitised should match the coordinates defined by the projection and map coordinate system. This omits the need to transform from an arbitrary design plane to real world coordinates. At the least, four registration points (typically IGDS cells at each mapsheet corner) should be provided to allow such a transformation.

4) Standardising design level definitions within a mapping project greatly assists the conversion process. The routine separating of themes into specified levels and the use of standard nomenclature for design files, assists in the orderly and complete transferral of data.

A raw GIS coverage is created from the design file using the *igdsarc* command. The default tics for this coverage correspond to the minimum and maximum coordinate values and must be repositioned exactly to the cells or monuments used to register the mapsheet. These are typically the mapsheet corners. The arcs making up the coverage are then edited, to correct for mismatched nodes, offshoots, duplicate or missing arcs, and unclosed polygons. This is done using the functionality of Arc Edit.

Topology is constructed once the digitising errors have been corrected. Attributes are then assigned to the polygon, arc or point features. Validation is undertaken to correct for topological and attribute errors. In many cases, digitising for the IGDS file has been done in a design plane with an arbitrary coordinate system. The resulting coverage will require transformation to the real world coordinate system (eg AMG) by *transform.* Metadata relating to each coverage is then collated and recorded.

A final basin-wide seamless coverage is created by appending the relevant coverages sourced from each mapsheet. Over 25 basin-wide coverages have been derived from the coverages created from the individual 1:250 000 scale mapsheets.

Table 1: Summary of IGDS to Arc Data Processing Steps

STEP	PROCESS	COMMANDS
1	Dearchive and prepare design file for reformatting	ustation commands
2	Conversion of design file to raw GIS coverage	igdsinfo, igdsarc
3	Registration of tics	arcedit snapping, $ID editing
4	Clean data of offshoots, duplicate arcs, unclosed polygons	arcedit commands, clean
5	Topology building	create labels (polys), arcedit commands, build
6	Identify and correct topological errors	intersecterr, label errors, node errors arcedit draw environment
7	Add and populate attributes	add item, arcedit commands
8	Validate and correct attribute data	arc plot, arcview, arcedit
9	Transform to real world coordinates	transform, project
10	Rebuild and final check of mapsheet coverage Finalise documentation	build textedit

MBTools - the project interface

The construction of the GIS database has involved the creation of over 400 coverages from the 26 mapsheets. AML-based routines were developed to streamline this data processing. These include tools to:

- partially automate the IGDS-to-ARC conversion
- add standard feature attribute definitions
- derive feature attributes from elements of the IGDS file
- display potential topological or attribute errors within an editing environment
- validate aspects of the final GIS coverage.

The tools are integrated into a modified version of ESRI's graphical user interface (ArcTools) called MBTools (Brodie, 1994). ArcTools is a menu-driven system that provides a general interface to the Arc/Info toolbox. The modular design of ArcTools allows the development of customised interfaces, by adopting or adding to a suite of available AML routines.

For example, populating the attribute tables of GIS coverages can be the most time-consuming task. AMLs were written to take advantage of features inherent within the original IGDS file. The layout of the menus for these tools are presented in Figure 1. During the *igdsarc* conversion, an info table (*cover.acode*) is generated to store the graphical properties of the elements making up the IGDS file. This includes parameters such as level, colour, weight, style and annotation text. The coverage attribute table can be linked to the *cover.acode* by creating a relationship using *relate*. This allows GIS features to be selected on the basis of their IGDS properties.

The *igdslevel* tool was written to take advantage of the fact that the IGDS-level of each GIS feature is stored in the related *cover.acode* file. The user inputs the name of the *cover.acode* file, the target item in the attribute table to be updated, and up to ten codes which relate to particular IGDS levels. For example, in this way all highways (level 1) can have type = 'H', secondary roads (level 3) have type = 'S', minor roads (level 4) have type = 'M' and so on.

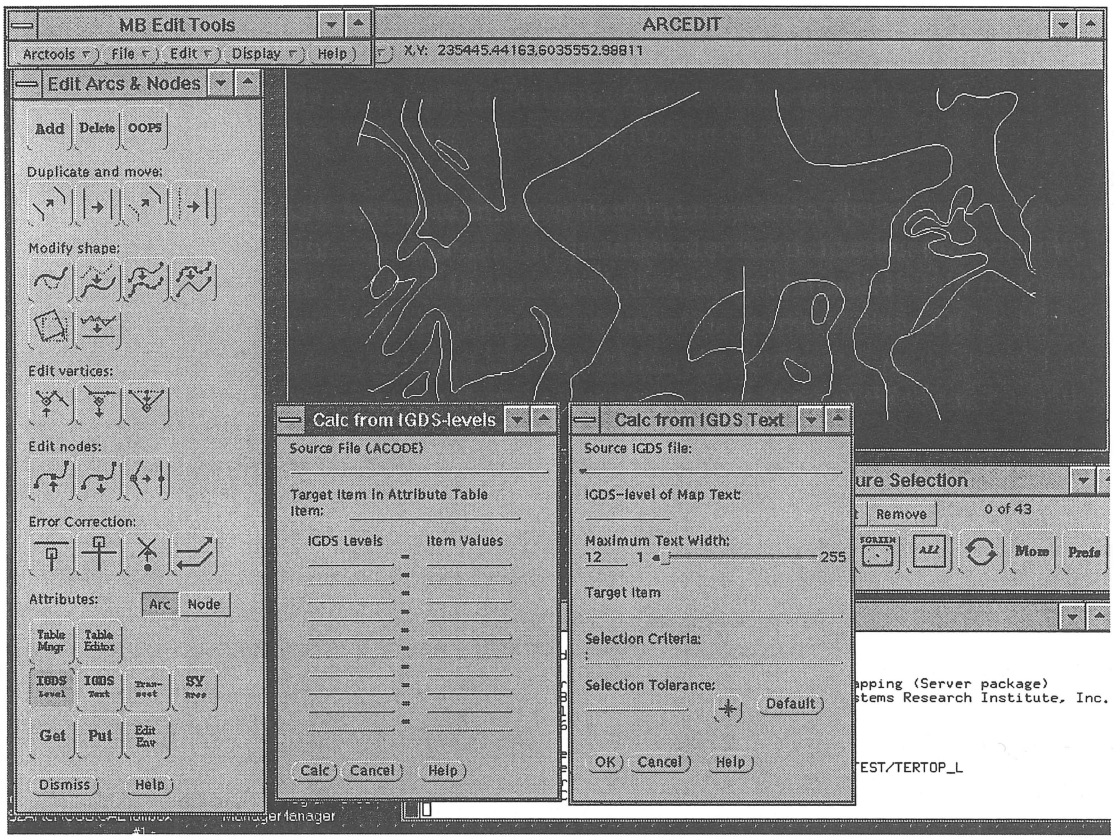

Figure 1: MBTools Menu Interface for IGDSLEVEL and IGDSTEXT tools

Within the *igdsarc* command there is also a mechanism to preserve information stored as map annotation in the source IGDS file. By using the *textpoint* option, the IGDS text is placed as a point positioned at the text origin. The first 12 characters of the text string are stored in the *igds-text* item of *cover.acode*. Text strings longer than the default can be accommodated by defining the *text_width* option of the *igdsarc* command. This is used to advantage in the *igdstext* tool. This AML was written to update attributes of contours, points or polygon labels based on the annotation depicted on the published map. By relating the *cover.acode*, the information stored in the *igds-text* item can be copied into the appropriate item of the coverage attribute table. In this way, contour labels and spot heights on the map can be transferred to the attributes of contours and points of the GIS coverage, respectively.

Other AMLs were written to assist in the highlighting of potential errors within the ArcEdit environment. These include the capability to colour code attributes, label contour values, plot potential label errors, colour fill polygons and emulate the published map, while editing the coverage. By giving the user greater flexibility in how the data is displayed, attribute and topological errors could be better highlighted.

Data Management

The GIS database is currently maintained in a standard directory structure based on the model of 'shared work areas' (Tucker et al, 1994). The work area contains common projection files, symbol sets, the AML-based tools and unix scripts as well as the GIS data. The structure and nomenclature of the MB shared work area is shown in Figure 2.

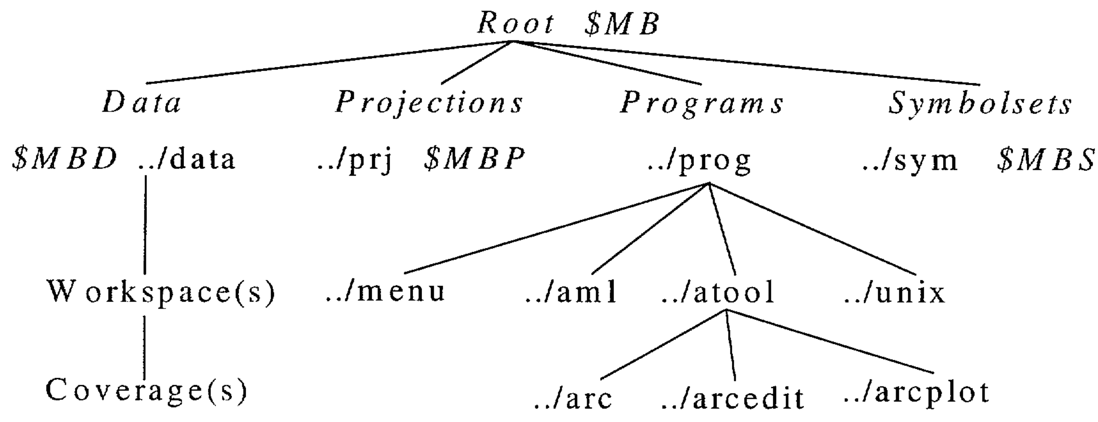

Figure 2: Directory Structure for the MB Shared Work Area

Everyone working on the GIS project is assigned to the Murray Basin group (*mb*). This allows simultaneous read access to the directory structure and access to the MBTools interface to *mb* group members only. Write access is vested in only the GIS data administrator for the work area - the *mba* user. With write access limited to a single user, data management operates in a controlled environment. Any *mb* user can copy a coverage and then perform updates on their version, but only the *mba* administrator can write the edited version back into the shared work area when required. In this way, the *mba* user has sole responsibility in maintaining the most current version of the database in the one location. A shared work area also allows AMLs to be used to automate archiving of export files for tape back up when a project milestone is reached.

Standards for coverage nomenclature, topology, projection and attribute definitions are established for the GIS database. AML-based tools were written to validate the coverages to these standards.

Metadata relating to each coverage is simply stored as a text file (Tucker et al, 1994). The file contents is based on the input requirements for the FINDAR directory system (Shelley, 1992) incorporating details on spatial identification, temporal coverage, currency, availability, lineage and quality. A standard documentation template was made available in the shared work area, as well as templates defining the data items of common coverages. The documentation file may be created, edited or displayed via the MBTools interface.

Future Directions

The Murray Basin Hydrogeological Map Series was ostensibly a cartographic project, with GIS technology only introduced late in its history. With conversion into a digital database, the utility of GIS was highlighted. This included greater capability in detecting errors such as wrong contour values, mismatches along mapsheet boundaries or deviations from the project's cartographic conventions. Hence, one use of GIS is quality control in complex multi-agency mapping programs.

More importantly, the advent of GIS technology has motivated a shift in how hydrogeological knowledge is made accessible to the wider community. In traditional mapping projects, much effort is expended in the cartographic process of how to *display* the information effectively on the published map. In this way, the map is the goal of the project. It is inherently difficult to access the data which was the source of the interpretation. For GIS projects, effort is expended on how hydrogeological information is *stored* - the underlying database is the project goal.

For example, the colour fill on the printed hydrogeological map depicts the groundwater salinity and yield characteristics of the aquifer - the colour (blue to pink) represents salinity classes and intensity (light to dark) indicates aquifer yield classes. This is the only data representation for salinity/yield that the map user can see and use. Within the GIS, the two themes are separated and stored in different formats - contours, TIN or raster. The borehole information used to interpret these datasets can be stored in a database connected to the GIS. In this way, the interpreted dataset is directly linked to the borehole data from which it was sourced.

With construction of the GIS database, a regional perspective of Murray Basin hydrogeology is suddenly achieved. A number of options are available for making the database accessible - as a range of common file formats for translation into other GIS systems, hardcopy output or packaged with a user interface on CD-ROM. A more flexible approach is taken for hardcopy output, allowing tailoring to particular client needs. Customised basin-wide maps of themes such as salinity hazard, potable and stock water supplies have been generated. The compilation of a CD-ROM package is currently under investigation.

Conclusions

It is recognised that management strategies within the Murray Basin are Community driven. For the Community to make informed decisions, there needs to be easy access to the hydrogeological knowledge base against which questions and scenarios may be evaluated. The published maps are one method of achieving this; the GIS database is yet another.

AML-based tools greatly enhanced productivity and reduced data errors for the Murray Basin GIS project. The use of check and display routines makes the compliance of project standards for coverage names, item definitions and attribute coding easier to achieve. Some tools automate repetitious tasks, significantly reducing the conversion effort. These tools are easily made accessible to the user by being integrated into a modified version of ArcTools. The use of template text files was a simple solution to recording metadata for the GIS datasets.

The GIS of Murray Basin Hydrogeology is an example of the transition from traditional mapping programs to digital databases designed to serve client needs.

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REPORT TO THE SECOND AUSTRALIAN NATIONAL FORUM ON GIS IN THE GEOSCIENCES ON THE 'MAP PRODUCTION WORKSHOP'

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1.0 BACKGROUND

The workshop was targeted at practitioners who are involved in designing, producing and publishing high quality geoscientific map products. It aimed to present a comprehensive update report on strategies employed by the respective state/territory geological surveys for digital map production and identify those issues which are fundamental to optimising the publishing process. The one thing we all have in common is the need to produce maps faster and it was with this in mind that the chief geological cartographers initiated the workshop as part of the GIS Forum at their conference in Perth in October 1994.

2.0 OBJECTIVES OF THE WORKSHOP

These were to:

- Review the status of geoscientific map production in Government agencies across Australia
- Identify some of the key issues confronting the mapping scientist through shared knowledge and experiences.
- Develop strategies to address the issues that are identified.
- Enhance the cooperation between those engaged in geoscientific map production

3.0 KEY CRITERIA FOR DISCUSSION

The main themes for discussion were:

-Agency strategy for geoscientific cartographic products.

-Map production 'tools'
  -systems used
  -longer term strategy for systems/applications
  -AMLs/MDLs etc
  -data integration

-The need for and use of standards, in a more specific sense, for example:
  -lineweights etc
  -screens/patterns
  -data transfer

-Prepress and publication processing

4.0 FORMAT OF THE WORKSHOP

1. A series of status reports by each state/territory representative against the key issues - a short period for Q&A to each speaker, together with a listing of issues which came out of each session.

2. Group discussion on the issues with a view to:
   -identifying solutions where they exist
   -establishing mechanisms to address the `hard issues'
   -appoint ownership of issues that need to be addressed

4.1 Registrants

Of the 40 people registered for the Workshop there was an even distribution between industry and geological surveys.

5.0 OUTCOMES

The primary outcomes from the workshop are as follows.

5.1 Data quality

We have an obligation to our customers to provide a quality product. There was a general recognition that accuracy is fundamental to the digital process. If we get this right the rest will flow.

5.2 Standards

Standards are fundamental to providing a quality product, ease of transfer, and so forth, but they also facilitate the production process. It was clear that most geological surveys and industry use AGSO standards and have developed some of their own. Industry acknowledges and encourages the role that AGSO plays in developing and fostering the use of standards and specifications for digital map production.

5.3 Printed products

One thing that was quite evident from the workshop was that while the demand for digital products is growing there is still a large customer demand for the paper product. It is important that we deliver the right products in a timely manner to this customer base.

5.4 Strategic approach

There is a commonality between the geological surveys with respect to their approach to digital product development. If ArcInfo is generally adopted, or to be adopted across the surveys, I am not sure whether this is the result of the master plan coming to fruition or simply opportunistic. Either way it provides the platform for enhanced cooperation and sharing of information. This is already occurring, but mechanisms have to be put in place to ensure this sharing occurs at all levels if we are to make significant gains in productivity.

5.4 Production issues

Many of the production issues confronting us are common problems because of the similarity between our systems. This provides a great opportunity for us to combine our skills and resources to address the hard issues. We need to define the problems, prioritise them and seek financial appropriation to address them.

5.5 Internet connections

Use of the Internet capability has to be a priority because it provides an efficient mechanism for information sharing. It is particularly useful for FTP'ing of files between us all, for instance NTGS send us their map files this way straight into our guest directory, no floppys, exabyte tapes to read, the data comes to us via Internet.

5.6 Data formats

Our customers are uniformly requesting data in MapInfo, ARC Export and to some extent DXF formats. This is pretty much in accord with the demand that other data providers are experiencing, eg AUSLIG and LIC.

6.0 ISSUES

The key issues which need to be addressed are as follows.

6.1 Standards for geoscience map products

There is a clear requirement for standards and specifications to be developed for the range of geoscientific map products, other than geological maps, for instance regolith mapping, environmental maps such as groundwater, natural hazards mapping, image products and so forth.

In essence we are talking about procedures for collection, data structure standards (such as symbols, colour, lineweights, patterns etc) for these map products. This issue could be picked up by a representative group from some of the geological surveys

6.2 Networking

It was agreed that electronic mail facilities between respective mapping practitioners is mandatory if we are to communicate efficiently.

A 'map production network' will be established between those on email to facilitate information flow, identify production problems and provide a mechanism for interactive group resolution.

6.3 On demand data supply and storage

There was a concern that effort is often being duplicated in the way we approach `on demand' requests for data. In some cases it is Departmental policy that when the customer demand for data is met the dataset is deleted rather than stored. Data storage is now relatively cheap in comparison with staff time and the policies in this regard need to be reviewed.

6.4 Project management approach

If we are to produce maps faster there can be no hiatus in the production process. This requires commitment by all who are involved in the process, which can only be achieved by introducing project management regimes.

6.5 Data quality statements

It was noted that Metadata is becoming increasingly important, especially when data is exchanged. There is a lot happening in this area, what with moves to STDS and the AMIRA Geoscience Data Model Project which we can link into.

6.6 Basedata

The perennial problem of availability, accuracy and cost of basemap data. 1:250K GEODATA is good for our final scale presentation but useless for data capture. We need digital base data at 1:100K and the effort associated with achieving this is having a significant impact, time wise and cost wise on our production. Considerably more lobbying is required to get the message through to the base data providers.

6.7 Size of our maps

Our geological maps are getting larger in format; for instance in some cases the marginalia exceeds the face of the map. This has cost implications, and is beyond most film writing and printing establishments. Perhaps we need to apply some lateral thinking to how we present our products.

6.8 Film writing

Many agencies have not achieved `routine' procedures for Postscript film writing, the files are characteristically large, in the order of 50Mb and as such have their own problems.

It was felt that there is a need for a device which will produce an EPS plot file to, say, a colour plotter without running through emulators. Many of the participants went away from the workshop with some options to test which could overcome these impediments.

6.9 Maintaining our data quality

It is vitally important that we have efficient management procedures for our data. This procedure is currently a bit ad hoc across the surveys and it was considered that cartographers are the most appropriate group to fulfil this custodial role, which in fact is the way two agencies have approached this issue.

6.10 Pricing policies

The workshop noted the inconsistencies across agencies for the ranges of digital data and services. While the ANZLIC initiative will address this in part agencies are urged to consider what is `reasonable' cost when marketing their basic datasets.

In conclusion, it was generally agreed that the workshop was valuable and achieved its objectives. We came away with some solutions as well as commitments to pursue some issues. All in all, the day highlighted the cooperation which is occurring between the Geological Surveys and AGSO under the NGMA initiatives.

PETROSEIS® MAPPING IN THE OTWAY BASIN:
An example of GIS in petroleum-related projects.

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Australian Geological Survey Organisation, Canberra.

Introduction

Geographic information systems (GIS) are a key element in the modern management of resources, whether they be natural resources (biological, petroleum, minerals, water, etc.) or human developments (urban infrastructure, pipelines, pastoral leases, stock, agricultural, etc.). In the oil and gas exploration industry and in the public management of these resources, geographic information systems are certainly key tools for both exploration companies and government departments. Explorers must have the tools to handle data (geology, geochemistry, and geophysics) in a particular lease area in terms of surface and sub-surface features. Government geoscientists must have the tools and skills to advise politicians, the public, and new players in a specific area of the regional geology and likely resources as a means of ensuring management practices are compatible with sustainable development.

The National Geoscience Mapping Accord (NGMA) is an agreement between Australian State, Territory and Federal Governments which enables projects to be undertaken which will generate an up-to-date series of geoscience "maps" across Australia in formats which are compatible with the computer systems now available for the handling and display of information. During 1991-94 the NGMA Otway Basin Project (Fig. 1) undertook work in western Victoria and southeast South Australia to improve publicly available information on the onshore Otway Basin (Finlayson, 1994). The partners in the project were the Australian Geological Survey Organisation (AGSO), the Geological Survey of Victoria (GSV), the Department of Mines and Energy, South Australia (MESA), and the Victorian Institute of Earth and Planetary Sciences (VIEPS) at Monash and La Trobe Universities.

This paper outlines the use during the NGMA Otway Basin Project of the Petroseis® program system as a GIS tool for interpreting and mapping seismic information on the sub-surface geology. Petroseis® has been used widely within AGSO for other petroleum-related NGMA projects including those in the Canning Basin, Officer Basin, and Bowen-Surat-Gunnedah Basins. It has proved to be a very useful tool in achieving AGSO's goals for mapping sedimentary basins.

Seismic profiling

The sub-surface structure of sedimentary basins, both onshore and offshore, is predominantly determined using seismic profiling methods along lines set out in a grid pattern. The basic principles of the method are greatly simplified in Figure 2. Onshore, the seismic source may be either vibrators or small explosive charges drilled into the ground; offshore, the seismic source is usually an array of air guns towed behind a recording ship. Reflected seismic waves are detected by arrays of geophones layed out on the ground or by a hydrophone streamer towed behind a ship. The seismic methods employed in the search for hydrocarbon targets have now reached a high degree of sophistication. Seismic profiling accounts for a high proportion of the exploration costs for oil and gas in any particular sedimentary basin prior to drilling.

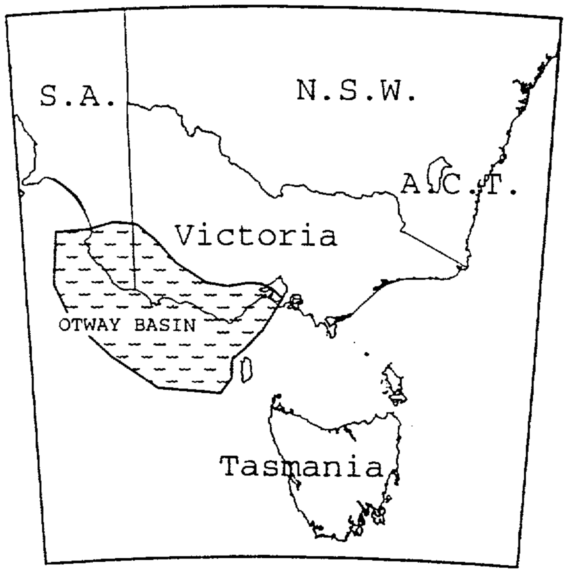

Fig. 1 - Location of the Otway Basin in southeastern Australia.

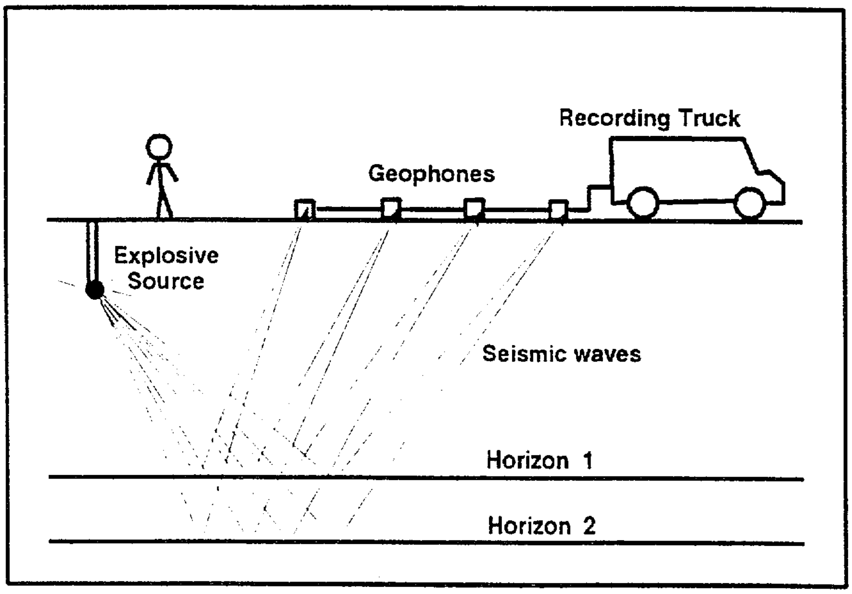

Fig. 2 - Greatly simplified illustration of the seismic profiling method of investigating sub-surface geology.

During exploration work, seismic reflection profiling data are recorded on magnetic tape. Data are then processed to produce seismic record sections (images) of sub-surface geology. An example of an unmigrated AGSO seismic section across the Yaloak Fault in the Otway Basin (Fig. 3) shows faulting within basement rocks at the basin margin. These data are displayed in two-way time i.e. the time it takes for seismic waves to travel from the source to a particular horizon and be reflected back to the geophone array. Output seismic images are usually available as both hard-copy (paper or film) sections and as digital data tapes/cassettes conforming to industry-standard formats. In Australia, State and Commonwealth legislation requires exploration companies to lodge a copy of all seismic data with the appropriate government department as a condition of their lease agreement. After a certain confidentiality period, which varies from State to State, these data are available for third party and public use.

Seismic data such those shown in Figure 3 are commonly interpreted in two ways:- 1) paper or film seismic sections are interpreted by geoscientists with relatively simple tools (coloured pencils and a calculator); or 2) digital data are displayed on a seismic work station and interpreted interactively using appropriated software and database systems. Regional seismic interpretations can be obtained from paper sections to determine the main features of basin structure and stratigraphy. However, in recent years interpreters working within a particular exploration lease area commonly use interactive work stations to identify detailed stratigraphic features and drilling targets.

Mapping sub-surface geology

The task of mapping sub-surface geology across a whole sedimentary basin using seismic profiling data presents significant problems for any organisation or company. There is often a considerable number of seismic profiles and the task of interpreting these requires considerable geological skill to identify and associate seismic reflectors with particular geological horizons and structures identified in outcrop or in drillholes. An example of number of seismic lines available from a sedimentary basin is shown in Figure 4 for the Otway Basin. Data along these lines have been acquired since the 1960s and most are available as paper records from State Mines Departments. The quality of the data varies enormously with recently acquired data being significantly more detailed than earlier data. However, in many areas of the basin only the older data are available and hence must be used to provide comprehensive map coverage for the whole basin.

The next major task for any sub-surface mapping agency is the organisation of a database to transform interpreted seismic sections into a geographic information system capable of producing maps and images of sub-surface geology. Petrosys Pty. Ltd., Norwood, SA, is one company which has specialised in providing software for the management of such information. Their Petroseis® programs are used widely in Australia, and increasingly overseas, to enable the information interpreted on seismic record sections to be managed on a basin-wide basis (Petrosys, 1993); "Petroseis® is a purpose built system for the management, analysis and mapping of interpreted seismic and general purpose mapping data". Interpreted seismic horizons on paper sections can be digitised and the data entered into an information database. Data can also be transferred from databases derived from interactive workstations using a variety of proprietary software.

Project staff associated with the NGMA Otway Basin Project decided early in the life of the project to use the Petroseis® software as a tool for mapping sedimentary mega-sequences across the onshore parts of the basin. All four partners in the project (AGSO, GSV, MESA, VIEPS) had access to Petroseis® programs or software compatible with the Petroseis® programs. It was important to employ a seismic line mapping tool which was capable of being implemented on a number of different platforms (Unix, VMS, and

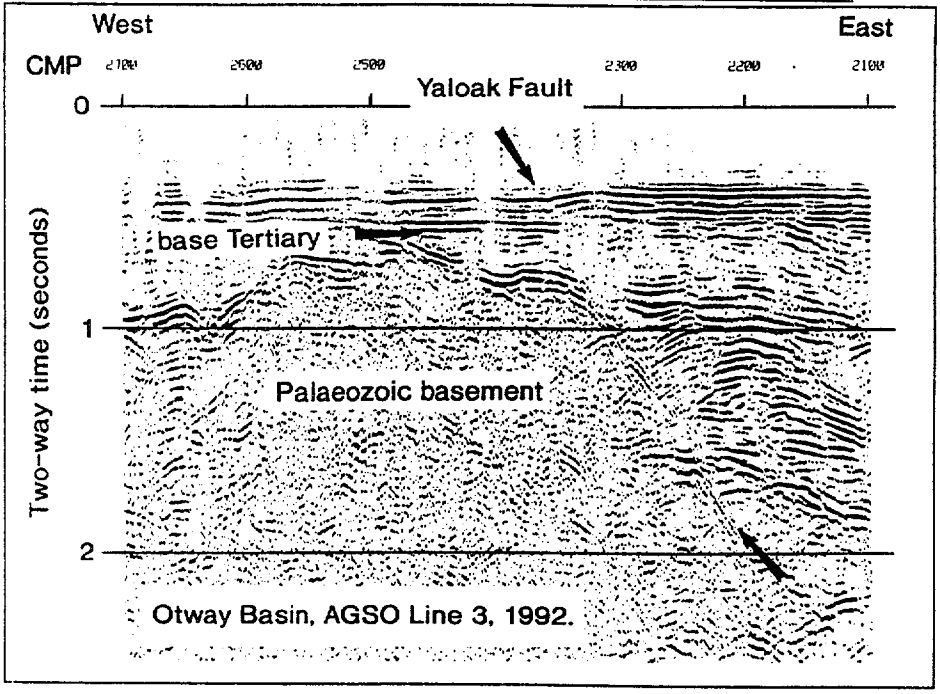

Fig. 3 - Unmigrated seismic section from 1992 AGSO Line 3 across the Yaloak Fault within Palaeozoic basement rocks in the Port Campbell Embayment area of the Otway Basin. Horizontal scale: 100 CMP = 6 km (CMP = common mid-point). Vertical Scale: 2 seconds two-way time = approximately 2.5 km.

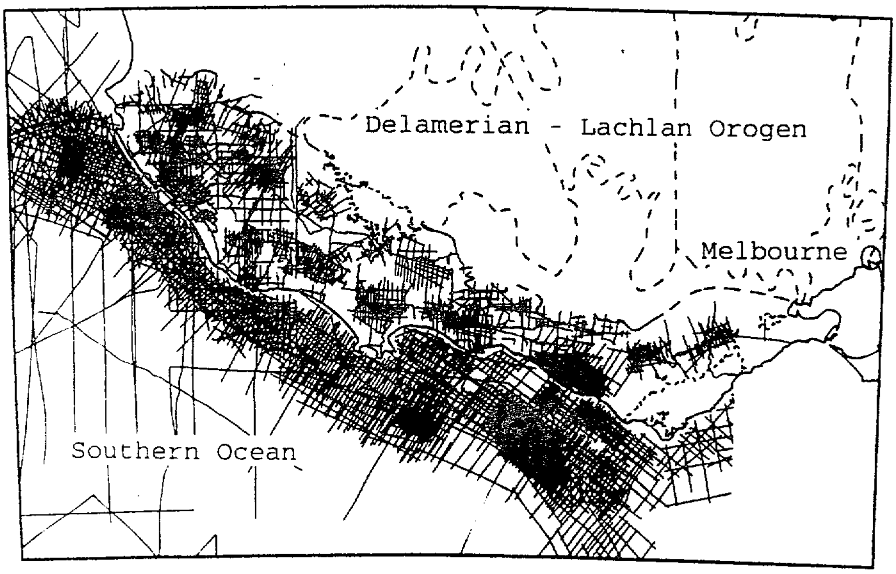

Fig. 4 - Seismic lines acros the onshore and offshore areas of the Otway Basin, southeastern Australia.

MS/DOS), was widely accepted by industry clients and could be interfaced with other mapping and database tools.

Otway Basin sub-surface mapping

Sub-surface mapping across the onshore Otway Basin was undertaken by four different institutions. For mapping purposes the basin area was divided into three parts; mapping in the western basin was undertaken by MESA, in the central basin by GSV, and in the eastern basin by AGSO and VIEPS. All interpreters in the various institutions had to be able to communicate and exchange data easily and effectively. This was done using floppy discs or Exabyte format tapes. Internet is another option for data transfer.

For the NGMA Otway Basin Project four major sub-surface horizons were chosen and mapped across the whole onshore area using a library of paper seismic sections. The four interpreted horizons were 1) top Palaeozoic basement, 2) top Early Cretaceous Crayfish Group, 3) top Early Cretaceous Eumeralla Formation, and 4) base Wangerrip Group. Details of the geological background to the mapping programme have been described by Finlayson (1994) and Perincek and Cockshell (1995). The number of horizons mapped in other basins of Australia has varied considerably depending on the availability of data and project requirements. For example, in the current NGMA project in the Bowen and Gunnedah Basins of Queensland and New South Wales about twenty horizons are being mapped.

Approximately 800 seismic lines were interpreted and digitised during the mapping of the onshore Otway Basin. An example of a digitised section from AGSO 1992 Line 3 across part of the basin is shown in Figure 5. At line intersections, misties could be checked by the Petroseis® program and had to be less than an accepted level, commonly less than 20 milliseconds, but this standard varied according to the quality of the data. Data were corrected within the program for different datum levels adopted by seismic surveys done by different exploration companies in different years. Fault structures also could be digitised; their continuity between lines was a matter of geological interpretation, depending on the line separation. Often gravity or aeromagnetic data were available as a guide to fault continuity.

A surface representation of each of the four horizons digitised in the Otway Basin was obtained by griding the two-way times from individual lines according to criteria set within the Petroseis® PGC program. Various grid-cell sizes could be adopted. A two-dimensional spline was fitted to the two-way times along the seismic lines. Initial coarse grid-cell sizes were iteratively reduced to the adopted size, chosen according to the average separation of seismic lines. An grid-cell size of 1000 m was adopted for most maps of the onshore Otway Basin. The griding program took into account the fault pattern which effectively breaks data into sub-sets, with surfaces being fitted separately from each side of individual faults. Smoothing parameters for the surfaces were chosen according to the final mapscale and seismic line separations. The extrapolation distance for the surfaces from individual datum points along the seismic lines could be varied (5000 m for Otway Basin maps).

Contouring of the various grids was also conducted by the Petroseis® PGC programs, again with smoothing and extrapolation parameters being varied according to the final mapscales. For the NGMA Otway Basin Project the final mapscales were 1:250 000 and 1:500 000, although for many areas where seismic line separation was less than 2-3 km, the data could be grided and contoured at 1:100 000 with little difficulty. A simple example of

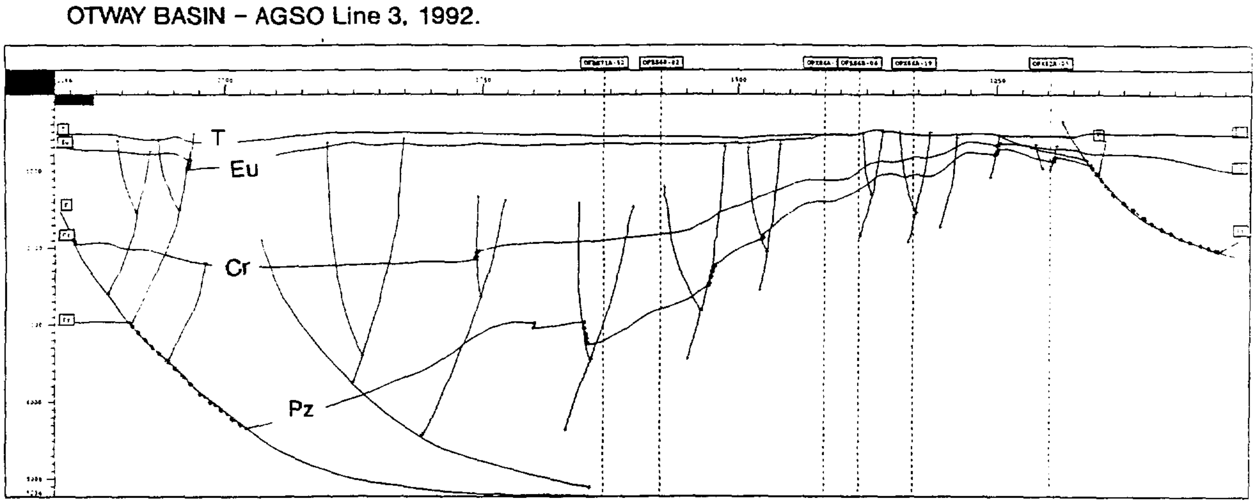

Fig. 5 - Digitized horizons and faults along AGSO 1992 Line 3 (length = 57 km) within the onshore part of the Otway Basin. T = base Wangerrip Group; Eu = top Eumeralla Formation; Cr = top Crayfish Group; Pz = top Palaeozoic basement.

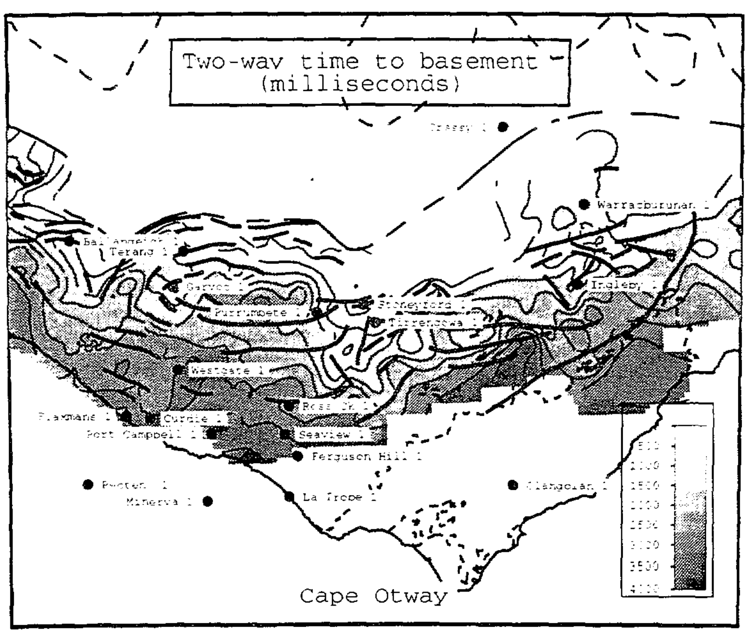

Fig. 6 - Simplified two-way time map to Palaeozoic basement for the eastern Otway Basin. Also shown are key exploration wells drilled in the region.

map output is shown in Figure 6. However, a true appreciation of the mapping and display potential of the Petroseis® programs can only be obtained when full colour maps are printed as hard copy or the grids and associated cultural and geological information are displayed on interactive work stations. The sub-surface geological detail in any particular part of the basin can then be examined more thoroughly. Grids could be readily exported for use with other proprietary software such as ER Mapper® (ERM, 1992).

Other forms of data were derived from the horizon mapping grids. Isochron maps (time thickness maps) of the three geological units between the mapped horizons (the Crayfish Group, Eumeralla Formation, and Sherbrook Group) were derived by subtracting grids. Using appropriate velocities, depth maps and isopach maps (thickness maps) could be produced. Output from the seismic database can also include profiles, "fence" diagrams, basin-wide pseudo-sections interpolated from grid data, and isometric displays as a means of illustrating particular features of sub-surface geology. A simplified map of major faulting across the onshore Otway Basin is shown in Figure 7.

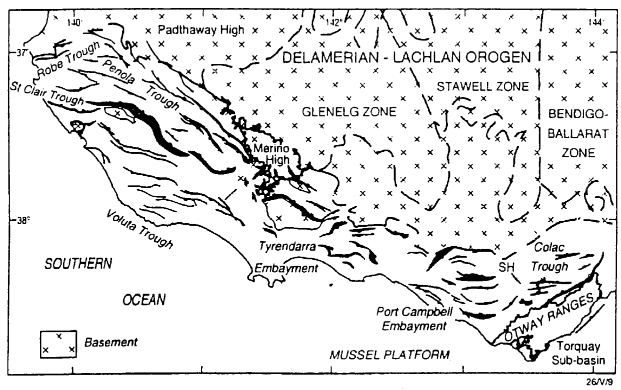

Fig. 7 - Major faults across the onshore part of the Otway Basin, southeastern Australia.

The term "cultural data" is used by the Petroseis® programs to categorise other forms of information such as point, line and polygon data (drillhole information, gravity data, towns, rivers, roads, bathymetric data, magnetic data, etc). These forms of data can also be grided and contoured provided they have an independent variable which can be mapped. Thus gravity, magnetic, bathymetry, elevation maps can be readily produced if desired.

Discussion

The Petroseis® mapping tools have proved to be a very robust and flexible way of producing seismic line databases and map products (both hard-copy and digital) for the NGMA Otway Basin Project. They perform the functions of a geographic information system (GIS) for the mapping of subsurface geology in sedimentary basins. The programs have been readily accepted by the exploration industry, State and Federal geological surveys, and academic institutions.

However, as with all proprietary software systems, there are potential difficulties with the archiving of data and information in forms that can be retrieved many years from now. While the company developing the software continues to prosper there is some assurance that data and information will be upwardly compatible with new software. However, a company's life cannot be assured for ever. Unless some widely-accepted data standards are adopted and an "active" archiving system is in place, the data and information will be vulnerable to changes in computing systems that make the task of data retrieval well nigh impossible. I am fairly confident that people will still be able to read the works of William Shakespeare one hundred years from now. Will they be able to read data from the NGMA Otway Basin Project? I hope so.

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PetroInfo: A GIS for Petroleum-Related Data.

Chris Parvey and David Palfreyman
Australian Geological Survey Organisation

The PetroInfo system was initially developed in order to test the feasibility of integrating, within the same system a diverse range of petroleum-related data. The platform selected to integrate data is ESRI's Arc/Info system. It was selected more for its range of tools permitting the input of information from disparate sources and its wide acceptance within industry. To date, information has been imported from platforms such as Petroseis, Intergraph, ER Mapper, AutoCad and Oracle. The data itself ranges from national datasets such as the petroleum titles, national petroleum wells, sedimentary basin, seismic, and depth to basement, to regional detailed datasets as the tectonic elements of the North West Shelf. The data types do not need to be restricted to vector based information, as Arc/Info can handle image and raster data. Two such data items have already been incorporated: the national gravity and magnetic anomaly maps.

Eventually, the system is expected to form a component of the Australian National Geoscience Information System (@ngis), and a repository for data collected both off shore and onshore.

By using the Arc/Info platform, the user of PetroInfo is able to use the viewing tool ArcView, also distributed by ESRI. ArcView provides a simple, easy to use graphical interface which can be learned in a minimum of time. Then, the petroleum geologist can move from a nation perspective of integrating broad regions, to zero into areas of petroleum potential - such as the North West Shelf. From the regional level, once the data sets have been established, the move can be made down to the sedimentary basin, and further to even the play concept. However, this is still in the future and will need to be developed in conjunction with other government agencies such as the Bureau of Resource Science (BRS) and state mines departments, and commercial companies such as Petroconsultants.

Further development of PetroInfo will concentrate on increasing the number of datasets and consolidating existing ones. Sets such as the sedimentary basins need far more data to be attached to them - and be better structured. For example, information such as age, thickness, dominant lithology and petroleum potential could all be added. Further more, sub-basins and crystalline blocks and other tectonic attributes need to be added. Similarly, input onshore from the states is needed.

As the number of data sets increases, along with the amount of data held against any set, the value of the system will increase. The ability to add data will result in a synergistic affect, which will allow spatial relationships between data to be explored.

Nevertheless, even at these early stages of PetroInfo's development the system has proved valuable in demonstrating the possibility and practical potential of a petroleum GIS as well a tool for data visualisation and data verification.

Recently, ArcView 2 was released by ESRI and the decision was made to make ArcView 1 shareware. This has permitted a widening of access to the PetroInfo system in AGSO. Data is held centrally on a Novell server while ArcView1 is installed on individual PCs. A basic 'view' of data is provided, opening with a map of Australia and contact numbers for AGSO.

From this opening view users create their own, and manipulate the data. As new coverages are added or updated, users can immediately access these through the ArcView 1 interface.

Illustration 1 shows a typical ArcView 1 session in PetroInfo. The viewer has zoomed into the northern region of Western Australia to analyse data relating to the Canning Basin which is selected and highlighted from the Sedimentary Basins cover. Petroleum titles are imposed for the region as blue boundaries. Other information displays are the Dampier fault (in brown), BMR seismic lines (in red) and finally, a selection from the PEDIN well database, extracting Blina 5 well, which is oil producing.

ArcView 1 can run on most PCs requiring only 4MB of memory and a 486 processor (386 needs a math coprocessor). Such PCs are now use by staff in the Marine, Petroleum and Sedimentary Resources division of AGSO and all can access the PetroInfo system. Hard copy output is possible to a number of laser plotters. Colour output is produced on a HP Design Jet 650 or Canon colour printer.

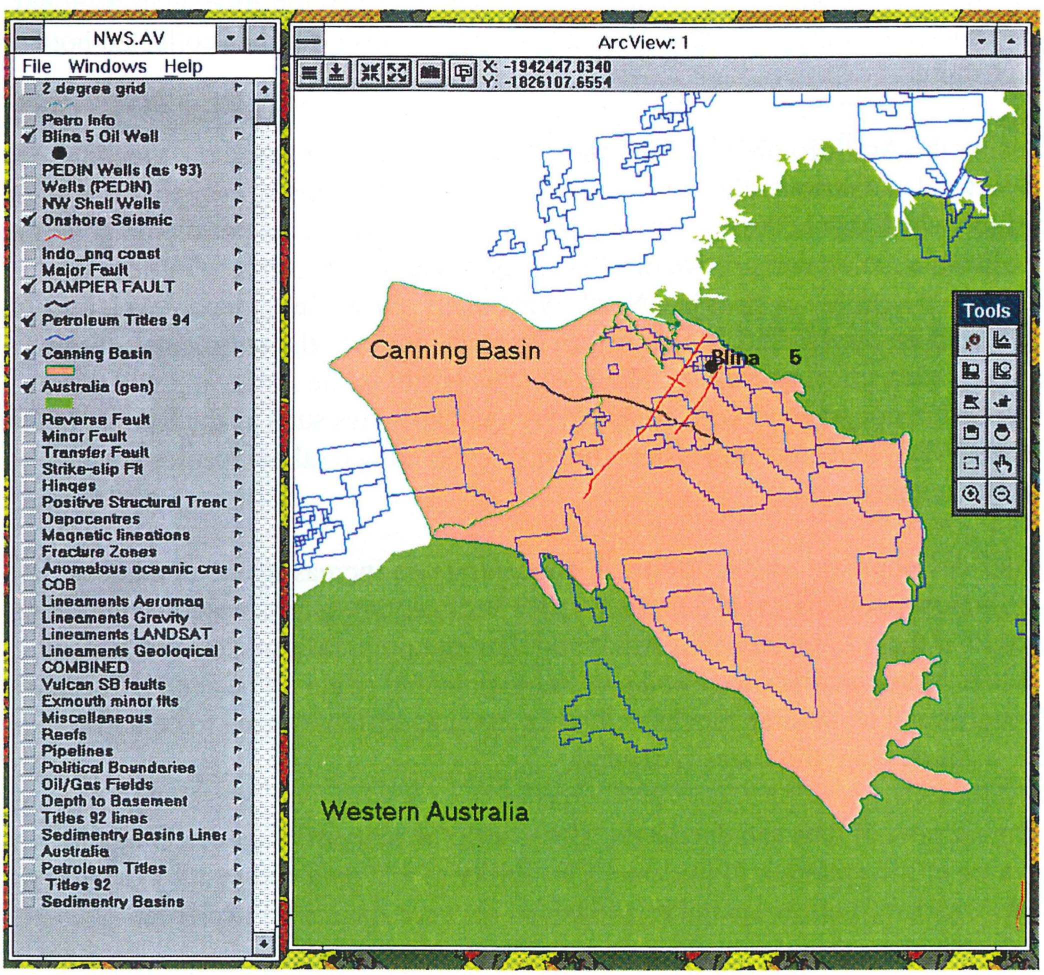

Illustration 1

Digital Geoscientific Data in Tasmania - Current Status and Future Directions

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Abstract: A project-driven approach to digital geoscience data acquisition has been successfully applied by the Tasmanian Geological Survey. This pragmatic "bottom-up" strategy for the development of a corporate data structure has resulted in rapid progress which would not have been possible with a traditional "top-down" design approach.

Geoscientific data is extremely diverse and includes both quantitative and qualitative information. The challenge in developing data structures for digital geological information is to preserve the essential content of the existing analogue data in a form which enables diverse and efficient query and manipulation in the GIS

Data structures developed by the Tasmanian Geological Survey to encode geological map information and geochemical data are described. The geological and geochemical data structures both encode attributes in a series of related tables which employ one-to-many and many-to-many links to efficiently and accurately represent original data relationships.

Introduction

The Tasmanian Geological Survey, in common with other government geoscience agencies in Australia, is in the process of converting an extensive legacy of analogue geological data into digital form for integration in a GIS (ArcInfo).

Digital geoscience data acquisition in Tasmania has been on a project-driven basis. Time and financial imperatives have led to a "bottom up" approach to the evolution of an overall corporate database structure. The "bottom-up" methodology has enabled significant progress, with limited resources, in a timeframe which would have not been possible with a more traditional "top down" design approach.

This paper describes the current status of a number of Tasmanian geoscience database projects, their development and future direction. The attribute schemes developed for Tasmanian digital geological maps and the structure of geochemical databases are documented in detail.

Digital Mapping Program

Standard scales of 1:250,000 and 1:25,000 have been adopted for digital geological map data in Tasmania.

The 1:250,000 map data is not simply a digital representation of existing published geological maps but is based on recent recompilation at 1:50,000 scale of all existing map data. Data for northeast Tasmania were released in 1994 and data for the northwest and southeast quadrants in April 1995. Data compilation and acquisition for southwest Tasmania will be complete by December 1995 (Figure 1). Recompilation of 1:250,000 information for the entire state has led to revision and synthesis of stratigraphic and age relationships across the island thus providing a sound basis for the compilation of more detailed 1:25,000 scale mapping.

Approximately 50% of Tasmania is covered by detailed systematic geological mapping, published at scales of 1:63,360 and 1:50,000. A significant proportion of this data was acquired in the 1950s, 1960s and 1970s. Detailed digital geological data is being acquired from manual recompilations of historical and recent information onto current 1:25,000 topographic basemaps. In addition to

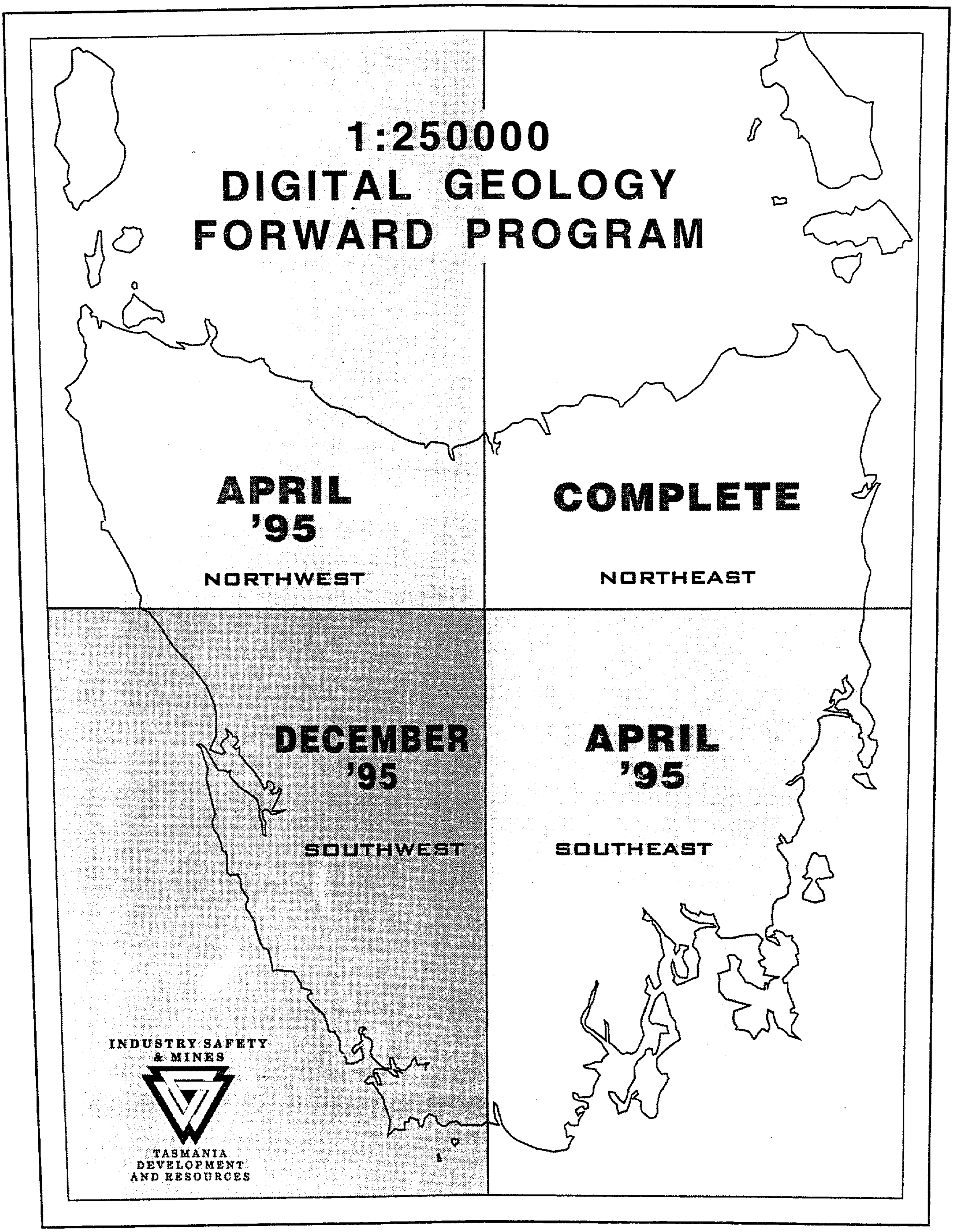


FIGURE 1. Data compilation and acquisition schedule - digital geology

geological arcs and polygons, all geochemical, mineral deposit, drillhole and structural geology data for each map sheet is also acquired. The initial focus of 1:25,000 data acquisition has been in northeast Tasmania, covering the northeast goldfields, and on strategic portions of the Mount Read Volcanics in western Tasmania (Figure 2). Data compilation and capture will proceed in the future on a project basis with ten new 1:25,000 map sheets compiled and digitised each year.

Spatial Data
Tasmania is fortunate, in comparison to other states, in that it falls almost entirely within a single zone of the Australian Map Grid (zone 55). The AMG coordinate system has been used for the spatial component of all onshore geoscience datasets. Base map data supplied by the Tasmanian Department of Environment and Land Management (DELM) has been used for data compilation and hardcopy output. Historical data, compiled on old, often inaccurate, base maps is manually recompiled onto the new base prior to digital capture. This process of recompilation is essential and ensures the correct relationships between important map features and geological boundaries or sample locations.

Attributes for Digital Geological Maps
Printed geological maps convey a wide variety of information to a geologist. It is essential that attribute schemes developed for digital map products effectively and accurately encode the range of complex, often qualitative, information in a form which enables efficient and comprehensive query and analysis operations.

Litho-stratigraphic units and some geological boundaries are portrayed explicitly on printed maps by means of different colours, overprint symbols and line types. Other information on a map such as sedimentological and contact relationships between adjacent units are typically implicit and their recognition relies on the knowledge and experience of the interpreter.

The combination of several layers of explicit information and additional implicit relationships makes digital encoding of geological map data more difficult than for other types of thematic maps. The challenge in designing an attribute structure for digital geological maps is to preserve as much of this typically qualitative information in a form which enables both complex and efficient query and manipulation of the data.

Despite the importance of geological map attributes there is little published information on suitable data structures and all organisations involved in capture of geological data adopt their own systems. To successfully store the full range of information, attributes must be given to both the polygons and to the arcs which make up the coverage. Attribute schemes for geological map data need to be able to encode all of the following information:

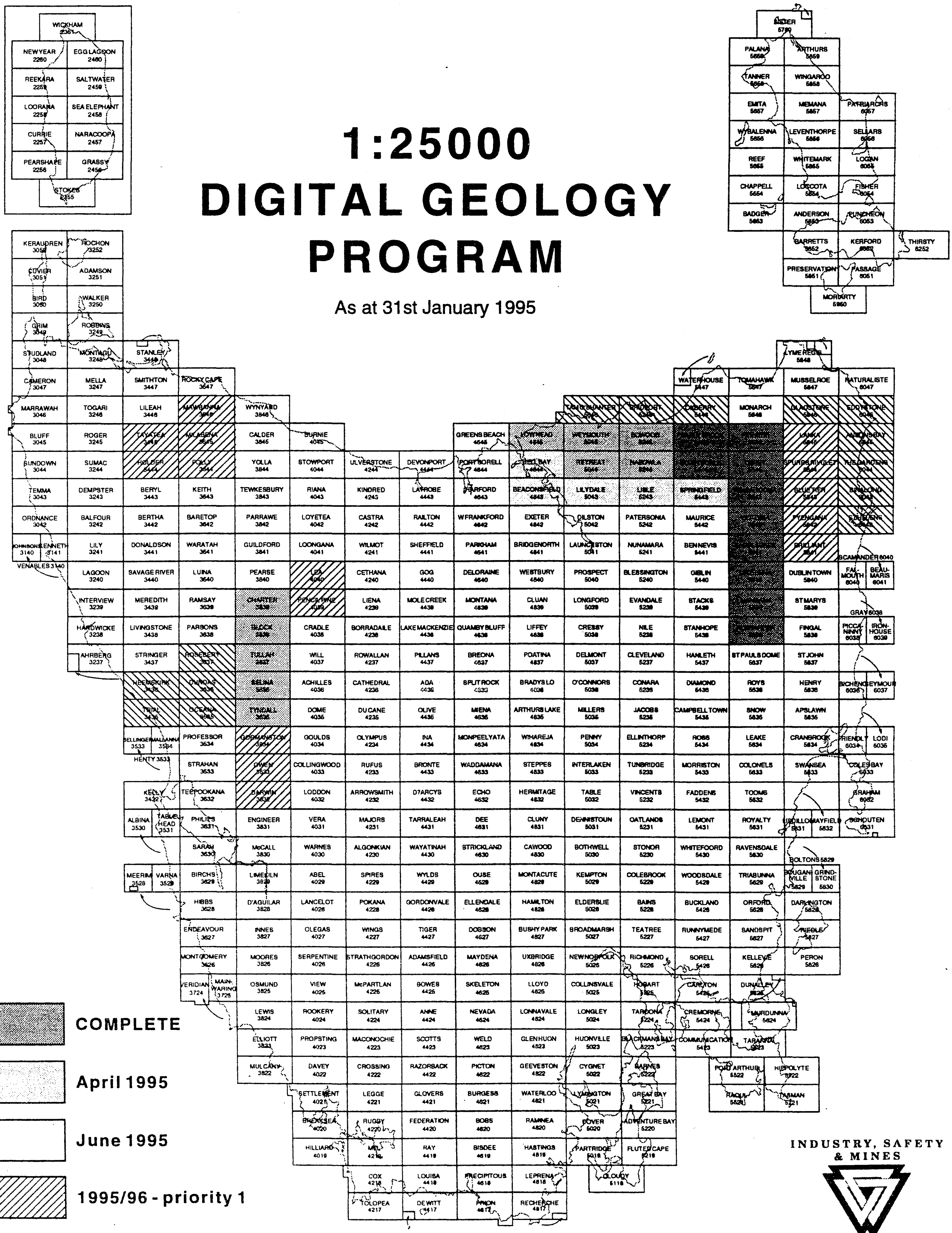
- Stratigraphic information
- Lithological data (including textural qualifiers)
- Age data (both relative and absolute)
- Mineralogy or alteration
- Sedimentological or genetic information
- Tectostratigraphic setting
- Relationships with adjacent units

An attribute scheme for Tasmanian digital geological maps has recently been developed and implemented by the Tasmanian Geological Survey. The coding scheme was created to provide a unified framework for digital geological maps at all scales across the state and was structured to readily facilitate a diverse range of data query and manipulation operations.

Polygon Attributes
Many organisations simply use the symbol on the printed geological map (eg: SDsm or Dgr) as the main polygon attribute, sometimes with a link to a lookup table which carries a free text

1:25000 DIGITAL GEOLOGY PROGRAM

As at 31st January 1995



COMPLETE

April 1995

June 1995

1995/96 - priority 1

1995/96 - priority 2

INDUSTRY, SAFETY & MINES

TASMANIA DEVELOPMENT AND RESOURCES

description of the unit. Map symbols usually convey a combination of age, stratigraphic and lithological information. Unfortunately symbols are typically not rigorously systematic and as a result database queries are often difficult or impossible. An additional problem is that map symbols are seldom unique and the same symbol is often used to represent different rock units on adjoining maps produced at different times or on maps of the same area at different scales.

Wright and Stewart (1989) recognised these limitations and proposed a coding scheme for geological maps based on the Digital Line Graph (DLG) format using multiple major and minor numeric codes of three or four digits to store the map attributes. This system has not been widely accepted due to the complexity of the coding scheme and the limitations imposed on the nature and quantity of descriptive information which can be recorded.

The problems associated with encoding geological map data are best illustrated by example. The following description is from the Zeehan 1:50,000 series geological map (Brown et al., 1994) and describes a single unit designated on the map by a number of polygons with a specific colour and overprint combination.

> "Interbedded purple, red and black dolomitic ***mudstone*** and ***siltstone***, and ***dolomite***, with lenses and interbeds of felsic volcaniclastic ***conglomerate***, ***sandstone*** and ***wacke*** and minor shard rich ***siltstone***. (Westcott Argillite correlate)"

In this case a single lithostratigraphic unit (the Westcott Argillite correlate) comprises seven different lithologies (indicated in italics) each of which has associated textural and morphological qualifiers. While this is an extreme example it is very common for a mapped unit to comprise two or more lithologies. A one-to-many relationship may thus exist between a map unit and its associated lithologies.

An additional complication in designing an attribute scheme to encode this information is that some categories such as stratigraphy and lithology are hierarchical (Currie and Ady, 1989; Mitchell, 1992) and map attributes must be structured to preserve this relationship. As an example: *basalt* is a *basic igneous rock* and hence database queries seeking *igneous rocks* or *basic rocks* should identify all units which contain *basalt.*

The polygon attribute structure used for Tasmanian geological maps is illustrated in Figure 3 and consists of a series of related tables linked by a common numeric code (RCODE). The structure of the database and the associated authority tables are described in detail by McClenaghan et al. (1994). A brief description of the fields in the lithology and stratigraphy tables is given in Tables 1 and 2.

A unique RCODE is assigned to each mapped rock unit in the coverage polygon attribute table. A single RCODE will typically apply to many polygons often on maps at different scales. Units are assigned incremental RCODE values based on broad age divisions, for example, all Cambrian rock units have values between 1500 and 2500. When a new geological map is captured, the stratigraphy table is searched to determine if each rock unit present on the new map has previously been defined. If the unit has been defined then the existing RCODE is used, if the unit has not been defined then a new RCODE is created and the appropriate entries made in the stratigraphy and lithology tables. In this way global stratigraphy and lithology lookup tables for the entire state are compiled incrementally as each new map is captured. At this stage in the data capture process geological inconsistencies between adjoining map sheets are also reconciled where possible.

Character codes have been used for the majority of the fields in the stratigraphy and lithology tables. Selection and query operations are more efficient with numeric codes but character based systems have the advantage that many codes can be selected to be intuitive combinations and hence are more readily accepted by the geoscientists who make the entries into the lookup tables for each new map sheet. Two character codes allow for a total of 650 unique combinations in each field which is satisfactory for Tasmanian geological mapping but three or four character codes may be more appropriate for continental scale databases.

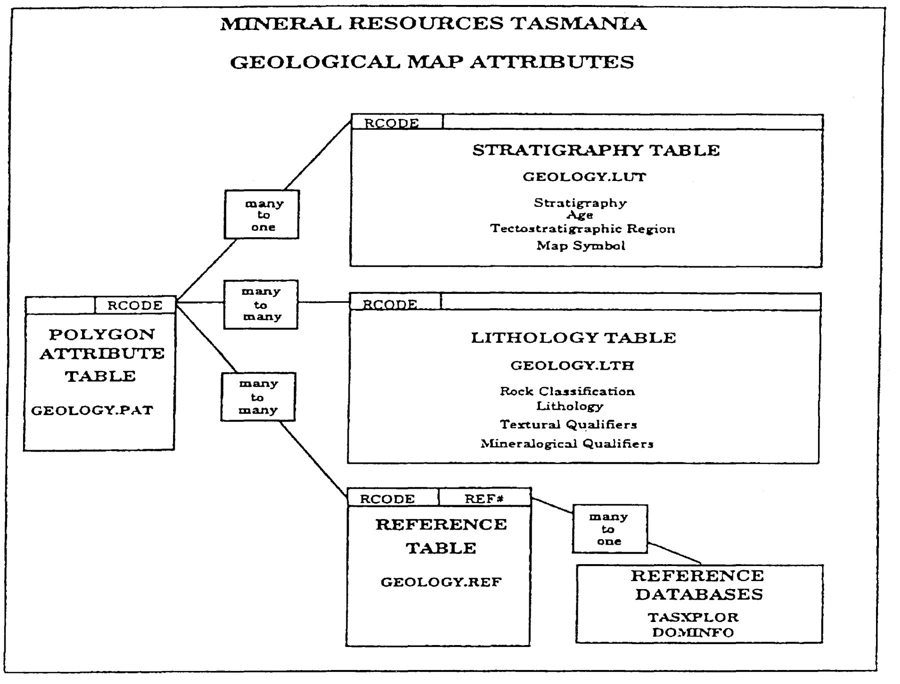


Figure 3. Attribute structure for Tasmanian digital geological maps

STRATIGRAPHY TABLE - GEOLOGY.LUT

Name	Definition	Description
RCODE	4,5,B	Unique rock unit code, used to link to the .PAT file and the lithology table
SYMBOL	8,8,C	The symbol which appeared on the published map eg: *SDsm, Dgr, COplc*
REGION	2,2,C	Tecto-stratigraphic region, eg: *AL-Arthur Lineament, BA-Badger Head Block*
SPGRP	2,2,C	Supergroup or major stratigraphic subdivision. eg: *MR-Mount Read Volcanics*
GRP	2,2,C	Group or equivalent. eg: *GG-Gordon Group, BT-Blue Tier Batholith*
FRM	2,2,C	Formation or equivalent. eg: *BU-Bundella Formation, PY-Pyengana Pluton*
MBR	2,2,C	Member or equivalent. eg: *PR-Poets Road Member, FH-Fonthill Sandstone*
ERA	2,2,C	Geological Era eg: *CZ-Cainozoic, PR Proterozoic*
PERIOD	2,2,C	Geological Period. eg: *NP-Neoproterozoic, CB-Carboniferous, PT-Permo-Triassic*
EPOCH	2,2,C	Geological Epoch. eg: *HO-Holocene, MI-Miocene, UP-Upper*
DIV	2,2,C	Subdivision of Epoch. eg: *LA-Late, MI-Middle, EA-Early*
MINAGE	4,12,F,3	Minimum age for the unit in million years BP.
MAXAGE	4,12,F,3	Maximum age for the unit in million years BP
DESC	200,200,C	Free text description of the unit, used for automated legends.

Table 1. Description of fields in the stratigraphy table. There is a many-to-one relationship between records in the .PAT file and records in this file.

Stratigraphic information is recorded explicitly for each rock unit with codes for supergroup, group, formation and member. If a mapped unit can be identified at a particular stratigraphic level such as formation then all parent categories (group and supergroup) must be encoded. To incorporate non-stratified igneous rocks into the stratigraphic framework, the term *batholith* has been equated to *group* and *pluton* to *formation*. The recursive hierarchical structure for stratigraphic data used by the Australian Geological Survey Organisation and described by Blewett and Ryburn (1992) has some advantages over explicit encoding but the implementation of queries in Info using this system is complicated and impractical.

LITHOLOGY TABLE
GEOLOGY.LTH

Name	Definition	Description
RCODE	4,5,B	Unique rock unit code, used to link to the .PAT file and the stratigraphy table
CLASS	1,1,C	Major genetic classification subdivision. eg: *S-sedimentary, I-igneous*
TYPE	1,1,C	Minor genetic classification subdivision. eg: *E-epiclastic, P-plutonic, V-volcanic*
COMP	1,1,C	Compositional subdivision. eg: *A-acid, B-Basic, L-lithic*
GENESIS	1,1,C	Depositional environment or formation mechanism. eg: *A-alluvial, C-cumulate*
LITH	2,2,C	Lithology code. eg: *SS-sandstone, BA-basalt, GD-granodiorite*
PROP	4,5,B	Proportion for this lithology, expressed as a percentage
TEXT	19,19,C	Textures, up to 3x4 character codes, space delimited. eg: *GRAD-graded*
MIN	15,15,C	Mineralogy, up to 3x3 character codes, space delimited. eg: *GRT-garnet*

Table 2. Description of fields in the lithology table. There is a one-to-many or many-to-many relationship between records in the .PAT file and records in this file.

A major complication in encoding stratigraphic information occurs where two formations, typically in different geographic areas, are considered to be equivalent. The current solution to this problem in ArcInfo is to maintain additional tables in Info for supergroup, group, formation and member which store the codes for units which are equivalent. Selection of correlate units is achieved by cursor processing and keyfile selection.

Age is encoded both in terms of standard geological time divisions and also by storing the minimum and maximum ages for each unit. Numeric age estimates enable storage of specific information such as radiometric or calibrated biostratigraphic ages and considerably simplify database query operations such as *'show all units which are older than Triassic'*. Where the exact age of a unit is unknown the IUGS age range for the appropriate period is used (Cowie and Bassett, 1989). Composite age codes such as *PT - Permo-Triassic* or *CO - Cambro-Ordovician* have been created to accommodate commonly used age ranges.

A single mapped unit can comprise several lithologies, as previously illustrated, and hence one-to-many or many-to-many relationships may exist between the polygon attribute table and the lithology table. There is one entry in the lithology table for each rock type recorded in the map unit. Selection of units in ArcPlot on the basis of lithological characteristics is most efficiently achieved by keyfile selection. The attribute structure for lithological data is hierarchical and explicitly encodes the parentage of each lithology. Multiple descriptive or mineralogical qualifiers may also be assigned to each lithology. An example of attribute coding for a complex lithostratigraphic unit containing multiple lithologies is shown in Figure 4.

Description

"Interbedded fine grained grey lithic volcaniclastic sandstone and black fossiliferous mudstone with occasional thin brecciated basalt flows"

Lithology Table

RCODE	CLASS	TYPE	COMP	GENESIS	LITH	PROP	TEXT	MIN
1545	S	L	L	P	SS	50	GREY FGND	
1545	S	E		P	MS	40	BLAC FOSS	
1545	I	V	B	P	BA	10	BREC	

Figure 4. Example of a complex lithological description encoded as multiple records in the lithology table.

In some cases the parentage of a particular lithology is uncertain or ambiguous. An example of this situation is low grade regionally metamorphosed sedimentary rocks which could be classified as either metamorphic or sedimentary. In this case the unit is assigned to both classes by duplication of records in the lithology table. Another common situation on geological maps is for a unit to be mapped as undifferentiated in one area and differentiated into multiple units in other areas. Undifferentiated units must inherit all of the characteristics of their component units. This is achieved by duplication of the appropriate records in the lithology table and hence these units may have a large number of lithology records.

The total storage requirements for the stratigraphy and lithology attribute tables is small. The Tasmanian 1:500,000 scale digital geological map comprises 13490 arcs which make up 5619 polygons (3.13 MB of spatial data). For this coverage there are only 46 records in the stratigraphy table (10948 bytes) and 110 entries in the lithology table (4180 bytes).

The reference table shown in Figure 3 provides a link between the polygon attribute table and existing databases which carry information about reference material in the Mineral Resources Tasmania library, including both published and unpublished reports. An individual geological unit may be referenced in many different publications and reports and hence a many-to-many relationship may exist between the polygon attribute table and the reference table.

Arc Attributes

The attributes associated with arcs in a geological map coverage must convey information about both the geological nature of the contact and spatial uncertainty. The coverage feature-id is used during data capture to store an integer code which indicates the characteristics of the contact.

On many published maps geological contacts are often classified according to only a limited number of categories such as: *position approximate, position inferred* or *fault*. It is generally not necessary on printed maps to specifically symbolise many types of geological boundary such as conformable contacts since this information is easily interpreted by a geoscientist. Unfortunately it is currently impossible to fully encapsulate the knowledge and experience of a geoscientist into a GIS system which could easily address questions such as *'show all intrusive contacts'*. In the absence of additional information this enquiry would require multiple queries to first identify all intrusive igneous rocks and then to eliminate faulted contacts and contacts with units which are younger than the intrusive body.

The utility of a digital geological map can be greatly improved by explicitly encoding the detailed nature of all contacts. Types of contact which should be encoded include: transitional, conformable, unconformable, disconformable, intrusive, normal faults, thrust faults, strike-slip faults and unknown contacts. Each of these categories should additionally be qualified to indicate the degree of spatial uncertainty.

The information content of the digital data can further be increased by use of the directionality of geological arcs to encode temporal relationships between adjacent units. In this case arc directions can be arranged such that the younger unit lies to the right of the arc. This type of information could be used to encode the interpreted intrusive relationships of plutons within a batholith where radiometric dates are not available or poorly constrained and all plutons have been encoded with the same age (eg: Devonian).

Exploration Geochemical Data

Simple tabular data structures are suitable for storing chemical data for whole rock geochemistry (McClenaghan et al., 1994) and for individual exploration projects where the range of elements measured and the analytical techniques are established and consistent. For regional compilation of existing exploration data this approach is not appropriate as the range of elements analysed and sample preparation and analytical details vary from one survey to the next.

The Tasmanian Geological Survey has recently commenced compilation of exploration geochemical information from across Tasmania including data from stream sediment samples, soil samples, water samples, rock chip samples and drill hole assay data. A common relational data structure employing one-to-many links between tables has been developed to accommodate each of these diverse datasets. The generalised structure of the database is illustrated in Figure 5 and the fields in the analysis table are detailed in Table 3.

ANALYSIS TABLE

Name	Definition	Description
SAMP#	4,5,B	Number which links to the sample tables
ELEMENT	2,2,C	The element or compound analysed. eg: *AU, ZN, PB*
TREAT	10,10,C	The treatment applied to the sample prior to analysis. eg: *-80 - -80 mesh*
ANAL	2,2,C	The analytical technique . eg: *FA - fire assay, NA - neutron activation*
LAB	4,5,B	The laboratory. eg: *1 - Analabs, 5 - Amdel, 14 - AGSO*
VALUE	4,12,F,4	The measured concentration (ppm)
MDL	4,12,F,4	The minimum detection limit (ppm) (-1 if unknown)

Table 3. Description of fields in the analysis table. There is a one-to-many relationship between records in the sample tables and records in this table.

The stream sediment, rock chip and soils sample tables store the information specific to each sample such as date, sampler, locational accuracy and links to reports and reference databases which describe other characteristics of the sample. For each incremental sample number there is one record in the analysis table for each element analysed. Using this data structure it is possible to store any combination of element, pre-treatment and analytic technique. A single analysis table stores all analytical data irrespective of sample collection method. At present these tables are stored in Info and database queries are accomplished by keyfile selection or cursor processing.

Conclusions

The development of an attribute scheme for Tasmanian geoscience datasets has provided the impetus for a thorough review of the stratigraphic, lithologic, age and structural relationships between the major rock units and provided a unified framework for subsequent digital mapping at all scales across the state.

Manual recompilation of historical geological data onto current topographic base maps, prior to digital capture, is essential to ensure the correct geographic relationships between base map features and geological entities.

Attributes for many geoscientific datasets are most effectively stored and manipulated in the GIS environment using a relational database structure employing one-to-many and many-to-many relationships between tables. This approach enables flexible, efficient and accurate encoding of complex and often qualitative information.

It is very important for the future of GIS in the geoscientific community that common data structures and standards evolve rapidly so that the lack of standardisation does no act as an impediment to the free interchange of digital data.

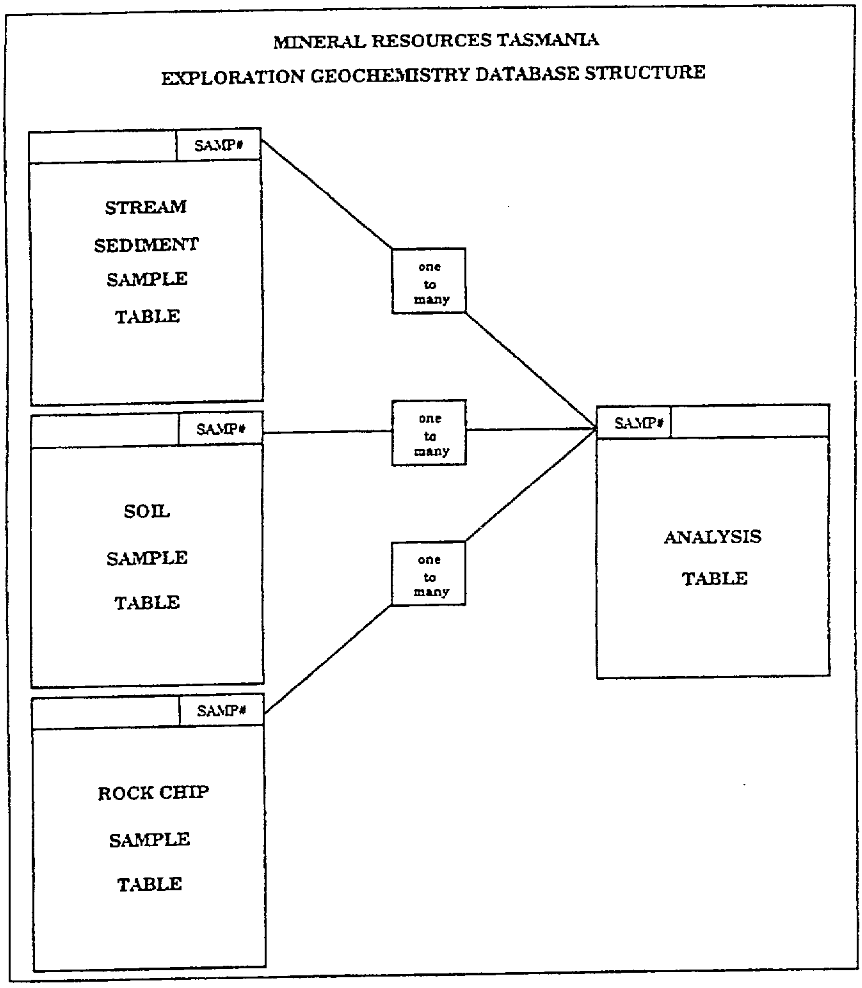


Figure 5. Exploration geochemistry database structure

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Selected Issues in GIS at Mines and Energy - South Australia

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Abstract: The development of GIS at MESA has progressed steadily from simple digital mapping in the 1980s to a substantial investment in data and its management and utilisation into the 1990s. Many issues determine the usefulness of geographic data when brought together within a GIS. These include the rigour of the spatial data capture, the establishment of the relationships between spatial features, the delivery of the data to its users and the documentation of its limitations. MESA has developed rules to assist in the implementation of its GIS. The essence of these rules is to provide users with the data they require in the format they require and within an acceptable time.

Introduction

MESA's approach to the development of geographic information systems over the past 8 years has been essentially "bottom-up". Databases were established as required and have evolved to meet changing needs. At MESA the focus has been on data acquisition and maintenance, and provision of the data to industry. The GIS began in the 1980s as simply digital mapping. MESA has avoided spending large amounts on application development, preferring to purchase off-the-shelf software and invest in data capture. The approach has proved successful as powerful, inexpensive and easy to use software has become available to promote and utilise MESA's now substantial GIS databases.

Software

MESA chose the UNIX environment for data processing and analysis, and the Windows environment for query and display. The software chosen was:

• Spatial database manager	ArcInfo
• Attribute database manager	Oracle RDBMS
• Query and display tool	ArcView
• Analysis tools	ArcView, ArcInfo, ER Mapper, Petroseis, and others

Spatial Data Acquisition

The traditional methods of spatial data acquisition, including digitising, scanning and GPS, are all used at MESA. After investigations and trials, it has been decided that scanning and vectorising is preferred over manual digitising, which is used only for small projects and minor maintenance. For large data capture projects, scanning provided a 200% productivity improvement and was less expensive. If clean base maps are not available, contractors are employed to prepare bases (usually by tracing) on stable material suitable for scanning. Themes can be sub-divided by the tracer at this stage, saving time in tagging spatial features later. The scanning and vectorising process is out-sourced at very reasonable cost. Advantages of this approach are that large volumes of data can be captured quickly if bases are available, tracing contractors need not be highly skilled, clean bases mean very little editing, and expensive hardware and software licences are not tied up with manual digitising.

The increasing use of GPS has presented some problems for GIS databases. At MESA, a GPS coordinate is not accepted without graphical verification. Large errors do occur, albeit rarely, with GPS readings. It has become necessary to store, particularly for point data, two sets of location coordinates, one representing the original, supposedly most accurate, absolute location - the other storing the coordinates of the location where the feature is placed in the GIS to ensure the correct relativity to other spatial features.

This introduces the important concept of "relative accuracy". It is the relationships between spatial features which are used by GIS software to perform its analysis and modelling. Spatial features must be located with the correct relativity to each other. Without this all that is left is a digital map. GIS can provide powerful query and modelling tools if the underlying data contains the correct relativity. For example, a point sample taken from a particular outcrop must fall within the outcrop polygon for the GIS to correlate between the sample and the outcrop. If intelligent results are expected from a GIS then the relationships between its spatial features must very closely represent the real world.

Currently, all available digital base data if used to position spatial features in their correct relative location. The original coordinate data is retained so that the relative locations can be reviewed as more accurate digital base mapping becomes available.

It is important to quantify the spatial accuracy of features to minimise the risks of data being used at scales beyond its reasonable capabilities. Spatial accuracy should be stored against each spatial feature if practical. However, if spatial accuracy is consistent for an entire database or a database "tile" then it is best stored against the database/tile itself.

Associated Attribute Capture

A traditional RDBMS is used for attribute data because of its recognised advantages of normalisation, security, integrity and rollback. However, application development in this environment is not a trivial task. MESA makes much use of Windows database packages, in particular Paradox. It has several advantages including:

- flexibility and user-programmability
- simple form design
- accommodation of many data formats
- portability for use on notebook computers for field work

Some data validation rules are implemented on the PCs, essentially to trap gross errors. The effort of duplicating all rules on a PC is not justified. Data is subsequently uploaded into the RDBMS through the complete set of validation rules, with errors reported and reject records not loaded. Our experience shows very few (< 1 in 200) rejected records using this approach.

GIS Data Management

MESA progresses through the usual database design phases of data modelling, logical design and physical implementation. Experience tells us that a time-consuming planning and design process is not productive. Effort should be concentrated on the data itself. It is the data that is the asset not the database design. With the data in digital form it is easily manipulated if need be.

Of course, the physical implementation should reflect the logical design as closely as possible. However, there are many reasons why compromises to the logical database design must be made - software capabilities, hardware and software performance being the main reasons. MESA has developed a policy where software response is a critical issue - an enquiry system must deliver results quickly or it will not gain acceptance. Simply upgrading to more and more expensive hardware is often not a sensible option. MESA will permit storage of redundant data, duplication of entire databases in different formats or coordinate systems, de-normalised data structures and duplicate subsets if necessitated by software response and display times. This is permitted on the condition that two rules are followed, namely that the master databases are identified, and the duplicating or de-normalising process is fully automated. The over-riding priority must be to provide the data to its users.

Coordinate Systems

It is an important yet difficult decision to decide on a coordinate system in which to store a spatial database. MESA has established a rule that the database shall be stored in the coordinate system in which it is best maintained. If digitising is required then AMG is probably required, if the source is GPS then AMG or geographicals are suitable, if data is maintained by "heads-up" digitising then store in the same coordinate system as the base mapping to which it is registered.

MESA's enquiry system uses geographic coordinates, so any databases whose master is in another system must automate the procedure to duplicate the entire database in geographicals. This is necessary presently because on-the-fly projection is too slow, but this is reviewed as software and hardware performance improves.

Geographical coordinates have advantages and disadvantages. The main advantage is that the entire State or Country can be displayed and queried without need for projecting. The major disadvantage is scale and distance distortion. However, this distortion is acceptable for screen display, with projection to an appropriate coordinate system only at plot time.

For special projects requiring analysis or modelling, data can be extracted and projected into the most appropriate coordinate system.

Spatial Data Directory

Out of necessity, MESA developed a directory of its digital spatial data. With gigabytes of data, hundreds of individual themes and distributed disk storage, keeping track of just what data MESA had was a difficult task. A directory was developed in Paradox to enable the spatial data to be indexed and for appropriate metadata to be collected. The directory is now maintained routinely as new data is collected or as aspects of the data change. The directory is able to answer questions such as the following:

- what databases do we have or are in the process of creating?
- where are they on the network?
- who is the expert to contact if I want more information?
- how accurate is the spatial data (± metres)?
- how reliable is the associated attribute data (%)?
- when was it last updated and when is the next update due?
- in what formats can the data be supplied?
- are there restrictions on its use or sale?
- are there any relevant enhancement proposals for this database?

The directory was developed in Paradox for the reasons of simplicity and ease of use. It is still a prototype and will evolve to meet any additional requirements. The directory is available across MESA on its Local Area Network. As there are only a relatively small number of entries, it is easily maintained and manipulated. Custodians are encouraged to maintain the entries relevant to their databases. Experience has shown that to ensure that the directory is maintained, users must be referred to the directory instead of expecting custodians to repeatedly answer similar questions about their data. It is now an accepted response to an enquiry about digital data to respond "I don't know. That information is in the Directory".

Conclusions

The experiences gained at MESA in the development of its spatial databases have suggested some rules to be followed.

- Plan in moderation. Circumstances and requirements change too rapidly to indulge in exhaustive planning exercises. It is the underlying data that is important and the effort should be in ensuring its suitability and accuracy. Use off-the-shelf packages wherever possible to avoid the time and expense of application development.

- Don't be afraid to compromise logical database design if necessary. If there are valid reasons to store redundant data or store duplicate copies of databases, then do so. Software performance will largely determine the successfulness of the end product.

- Maintain a directory and essential metadata. It is not a difficult or time-consuming task and will be invaluable in ensuring the availability and responsible use of the data.

- Give users what they require.

REGIONAL GEOCHEMICAL MAPPING USING GIS

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ABSTRACT The Geological Survey Division of the Department of Minerals and Energy (WA) has been allocated \$3.75 million over the next three years, with \$1.25 million in 1994, to complete a systematic regional geochemical mapping project.

In 1994, the Project involved the sampling and analysis of drainage sediments and the mapping of superficial materials (regolith) on four 1:250 000 scale map sheets. One sheet is now complete with the other three in various stages of completion. The sampling ratio is approximately one point per 16 km^2, representing a total of more than 4000 points over an area of 64 000 km^2.

One broad objective of the Regional Geochemical Mapping GIS Project is to store data collected in the field in such a way so as to permit its use within a GIS. The database is an integral part in the production of hardcopy maps and digital information. These products include digital data extracts and presentation of data in hardcopy form including the regolith, site location and the results of chemical analysis of 48 elements.

The 1:250 000 scaled maps can, in conjunction with other base information, be used in exploration programs for the identification of specific areas of the state with potential for undiscovered mineralisation and the provision of base chemical information for use in agricultural and pastoral activities.

INTRODUCTION

The Regional Geochemical Mapping GIS Project is the first regional geochemical mapping project undertaken by the Western Australian State Government. It is a new Department of Minerals and Energy (DME) initiative, managed by the Geological Survey Division (GSD). The Project is designed to assist the mining industry in mineral exploration and to help identify agricultural and pastoral needs. Four 1:250 000 scale maps were sampled in 1994 and a similar number will be sampled in 1995 according to priorities following consultation with the mining industry. Figure 1 shows the scheduled map sheets.

One of the Project's broad objectives is to store the geochemical sample and analysis data within a GIS for spatial analysis and the generation of a variety of products, including the raw data, digital map data and hardcopy maps.

The MENZIES 1:250 000 scale map is the first in the series. The MENZIES region is situated about 525 kilometres northeast of Perth and about 130 kilometres north of Kalgoorlie. The region has a semi-arid climate with a mean annual rainfall of 250 mm. Most of the area is located between 360 and 500m ASL and generally increases in elevation from southeast to northwest (Kojan and Faulkner, 1994).

The Geological Interpretation plan (Figure 2) has been compiled by Kojan and Faulkner (1994) from "Granitoid geology of the Southwestern Eastern Goldfields" (Witt, in press) with modifications in the Melita area based on the "Gold mineralisation in the Leonora-Wiluna region" (Hickman, in prep).

The field work for MENZIES commenced in February 1994 and the final data and map products were published in December 1994. The adjoining 1:250 000 scale map, LEONORA, is scheduled for publication at the end of April 1995. This will be followed by the PEAK HILL and GLENGARRY sheets in July and September 1995 respectively. It is anticipated that one sheet will be completed every three months.

SAMPLING

Geochemical mapping requires the identification and mapping of superficial materials (regolith) boundaries, and the sampling and chemical analysis of such materials taken at regular intervals over a large region. In the eastern goldfield region the regolith is deep, 20 to 100m where outcrops are widespread and mostly weathered. This restricts the use of conventional geological mapping and increases the need for geophysical and geochemistry as exploration tools (Butt, Lintern, Robertsen and Gray, 1993).

On the MENZIES sheet there has been 134 geochemical projects recorded in the Department's WAMEX database of company open-file reports from 1967 to 1992 (Figure 3). These projects contain details of sampling at a local scale. This, together with the fact that only an average of six elements were sampled for, restricts the use of these datasets in mineral exploration.

The sample density for the Project was determined at a ratio of approximately one sample per 4 x 4 kilometre grid (16 km^2). A total of 1072 points were collected and analysed for MENZIES. The sample medium included 'laterite' outcrops, soils, stream sediments and salt lakes.

Sites were located on the ground using Global Position System (GPS). The system of recording location co-ordinates was not automated but the GIS proved an invaluable tool in validating this location information (Figure 4).

ANALYSIS

The samples for MENZIES were analysed at the Amdel Laboratories in Perth. Eight different sample analysis methods were used and forty eight different constituents were determined (Table 1).

To check whether results reflected genuine geochemical variations, randomly selected sites were revisited to verify that location and sample details were collected correctly. Reproducibility was controlled by reanalysing the same sample site using a different laboratory, in addition to checking against the usual laboratory standards.

DATABASE

The data was initially loaded into Microsoft Access tables. This provided an inexpensive method of testing the aspatial database model before development of a database within an Oracle environment. The entity relationship diagram is shown in Table 2. The tables contain the unique sample number for each site, easting, northing, site attributes such as geology, regolith material, analysis batch number, and the chemical analysis results for each of the major and trace elements listed in Table 1.

SiO_2	Pt	Co
Sb		
TiO_2	Pd	Cr
Sc		
Al_2O_3	Ba	Cu
Se		
Fe_2O_3	Be	Ga
Sr		
MnO	Cl	In
Th		
MgO	F	La
W		
CaO	S	Pb
U		
Na_2O	Ag	Li
V		
K_2O	As	Mo
Y		
P_2O_5	Bi	Nb
Zn		
LOI	Cd	Ni
Zr		
Au	Ce	Rb
Sn		

Table 1 Constituents sampled for at each site.

The MENZIES field data were converted to comma separated value (CSV) files from the Access database for down loading into the GIS via floppy disks using 'sneakernet'. However, datasets from future 1:250 000 scale maps will be transferred directly across our Local Area Network (LAN) from Oracle database tables using the GIS database integrator capabilities. This will ensure that the latest data can be accessed by the GIS at any time.

Other components of the Project's spatial database includes the Regolith material map, stored as coded polygons in the GIS, a simplified version of the geology over the sheet area, the company open file (M-Series) report data stored as project boundaries linked to an aspatial table for cross-referencing and point data containing known gold mineralisation over the sheet area.

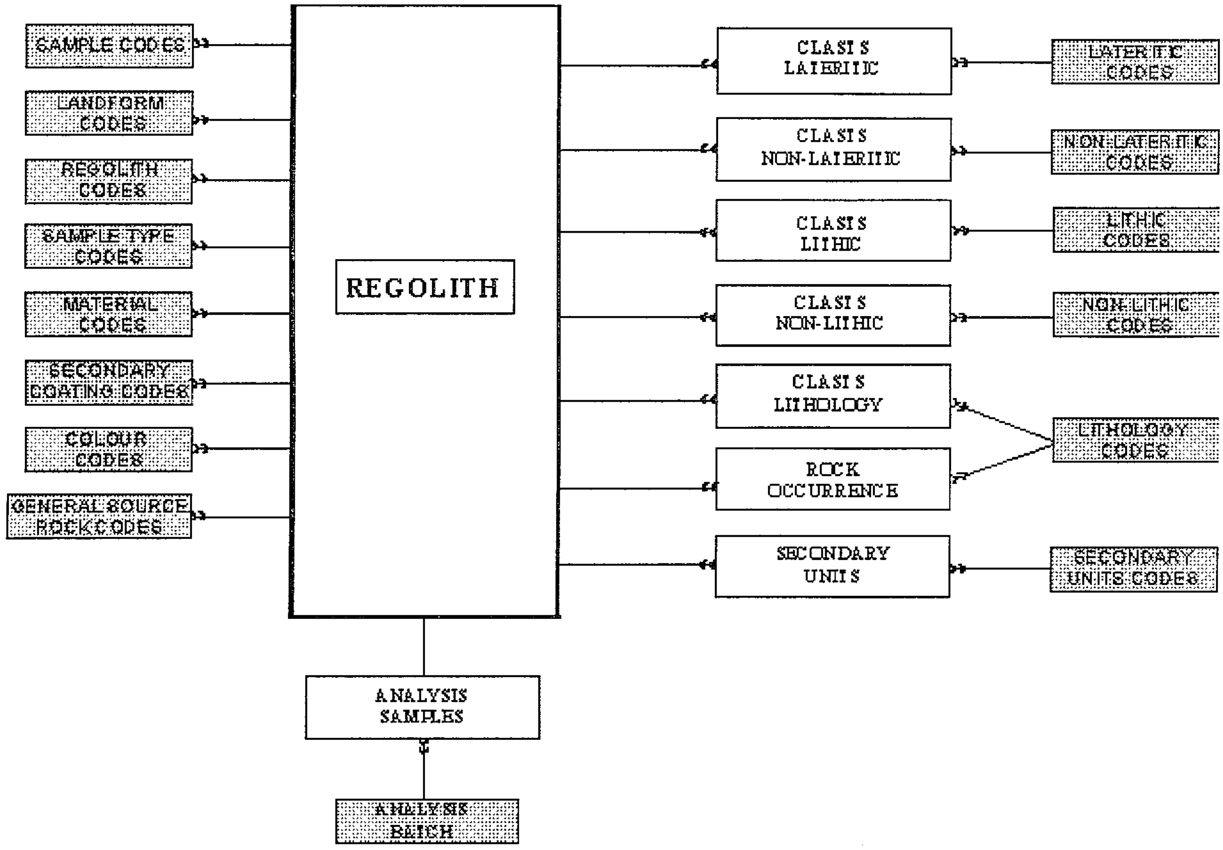


Table 2 Geochemistry Entity-Relationship Diagram

DATA PRESENTATION

The Project provided the opportunity to establish a new method of publication of the Geological Survey products. Traditionally GSD map products were designed as a lithographic hardcopy. This Project was a major breakthrough in using GIS technology to produce a variety of map and digital products.

At the outset it was unclear what methodology would produce a map which best represented the data to potential users. The MENZIES sheet has required a steep learning curve and through it many procedures have been set for future sheets. However, as the mapping process for these products improve, other techniques will be incorporated to provide a more refined product.

The maps are generated through Arc Macro Language programs (AMLs). By resetting global variables, a number of products can be quickly generated for the new sheets once the data becomes available.

Maps were produced using Arc/Info (Rev 6.1.2) on Sun workstations. The maps are produced on a HP 650C inkjet plotter. This provides a faster and more flexible mapping output compared to traditional lithography, with only a slight loss of cartographic quality. Maps are now produced on demand in smaller quantities, which is a time and cost saving.

Regolith Materials Map (Figure 5).

This map product is not easily automated in that the definition of boundaries and unit codes relies heavily on interpretation from Thematic Mapper images, aerial photographs and field data. The polygons were digitised using Microstation software. The polygons and unit labels in the DGN formatted files are down loaded into Arc/Info. The unit label is added to provide a reference to symbology and full descriptions.

With an ultimate aim of providing seamless regional regolith materials data, interpretation across sheet boundaries is essential for polygon consistency and unit definition, for this reason the polygon boundaries are usually edited several times before the final product is approved for publication.

While it can be a lengthy process, the GIS has proved an invaluable tool for validating and proofing the regolith boundaries and coding.

Elements Distribution Maps (Figure 6 - 8).

After presenting the geologists with a range of point data representations, including sector diagrams, proportional spot sizes and contour diagrams for selected elements, a proportional spot size method was chosen as the standard display method for element distributions for the Project.

The spot symbols were scaled by setting minimum and maximum data values to be symbolised by precise spot sizes, and scaled using an exponential value of one to size intermediate values. This linear scaling factor allowed the element values to be estimated easily from the map in relation to the map legend.

Using a linear scaling factor rather than one that approximated an area scaling factor emphasised higher values of element occurrences, whereas the area method tended to equalise values across the data range.

Although these methods give a true indication of the analysis results, a preferred approach is to standardise point data in relation to background regolith types, before symbolising. The technique intended to be used on subsequent map sheets is to calculate the arithmetic mean of all sample points within each regolith type and using only the values equal to or greater than the average, translated as percentiles for mapping. This method eliminates values of less than average magnitude from display.

Gold Mines and Prospects with Regional Gold Geochemistry Map (Figure 9).

The map shows a surface generated from the gold (Au) values obtained from the analysis superimposed with gold mines and prospects for the MENZIES 1:250 000 area.

The surface was generated using Arc/Info TIN, where the analysis values were treated as 'z'. From the TIN a Lattice was generated with a cell size of 200 metres. The final colour map was created by gridshade using seven manual classifications.

Miscellaneous Maps

A variety of other maps have been produced including multiple elements at one sample point shown as a sector diagram, overlays with TM imagery, contours generated from geochemical analysis and surface maps for various elements.

The results of portraying the data in these ways did not meet the geologists expectations and have not been included in our 'standard product' atlas. Further work in this area is continuing.

ArcView 2

DME has adopted ArcView as its strategic Desktop Mapping tool for the dissemination of GIS databases to the users. Through the Avenue programming language (which is a peripheral product to ArcView), scripts have been developed to tailor the application to users' specific needs.

The following applications were developed for the Regional Geochemical Mapping GIS Project for use by Geochemists.

Index Map

At startup users are displayed a map of the State of Western Australia with each of the geochemical map sheets. The map sheets are hot-linked to their respective views. To move from view to view it is a simple matter of selecting the hot-link tool from the tool bar and clicking on the desired map sheet. To bring back the Index Map users can click on an item in the menu.

Changing Projection

To change the projection of a view in ArcView users normally have to scroll through a number of menus and have a knowledge of such parameters as Central Meridians, Standard Parallels, Scale Factors, Spheroids etc. Therefore, an option added to the ArcView menu allows the user to quickly change the projection of a view to Transverse Mercator (AMG), Albers Equal Area or back to Geographic.

Spot Symbol Ramping

Most of the final geochemical map products require a scaled spot ramp for each element showing the value at each sample point. To provide a function which ArcView does not yet have, scripts were written to ramp spot sizes and assigned a button on the button bar. Users have the choice of two types of scaling, Linear (based on the diameter of the circle) and Exponential (based on the Area of the circle).

Grid Generation

As ArcView does not yet have the functionality to produce grids for views and layouts, a script was written to allow users to draw a simple grid in their view to help 'locate' themselves or provide an idea of scale when viewing a magnified portion of the view.

Element Histogram

This is an example of adopting one of the sample scripts provided with Avenue. When creating charts from tables, ArcView will produce one chart element for each unique item in the table. Using one of the sample Avenue scripts, a button was created to produce a classified histogram of a table. This is useful to Geochemists because they can view trends and cut off figures before requesting final map products from Arc/Info.

Adding Themes

When adding themes to views, users normally need to know the source and name of the file. In some cases these are not obvious. The 'add theme' button has been modified to display the map sheet names, standard theme names and classification item. The theme source and name are found and loaded automatically by the script.

CONCLUSION

The project was undertaken by the Department with a clear idea of the objectives: collect, collate and present the interpreted data to assist industry in mineral exploration and to assist agriculturist and pastoralists.

The Project has shown that GIS and inkjet technology can provide good quality map products. The system provides a flexible and time effective alternative to lithographic products.

In addition, the GIS provides a homogenised environment to integrate geochemical, geophysical, remote sensed information, all of which are an integral part of exploration techniques.

The ArcView applications which have been developed will enable geochemists to view their data spatially, and perform simple data analysis and displays. This will aid in identifying data trends and anomalies, and provide an indication of likely map products they may be likely to require.

REFERENCES

Butt, C.R., Lintern, M.J., Robertson, I.D., Gray, D.J., 1993, Geochemical exploration concepts and Methods in the Eastern Goldfields Province, Australian Geological Survey Office.

Hickman, A. H., in prep, Geology and gold mineralisation in the Leonora-Wiluna region; 1:250 000 map, Western Australian Geological Survey.

Kojan, C. J., Faulkner, J.A., 1994, Geochemical Mapping of the Menzies 1:250 000 Sheet, Western Australian Geological Survey.

Witt, W.K., in prep., Granitoid geology of the southwestern Eastern Goldfields: 1:500 000 map: Western Australian Geological Survey, Report.

REGIONAL GEOCHEMICAL MAPPING GIS SCHEDULE

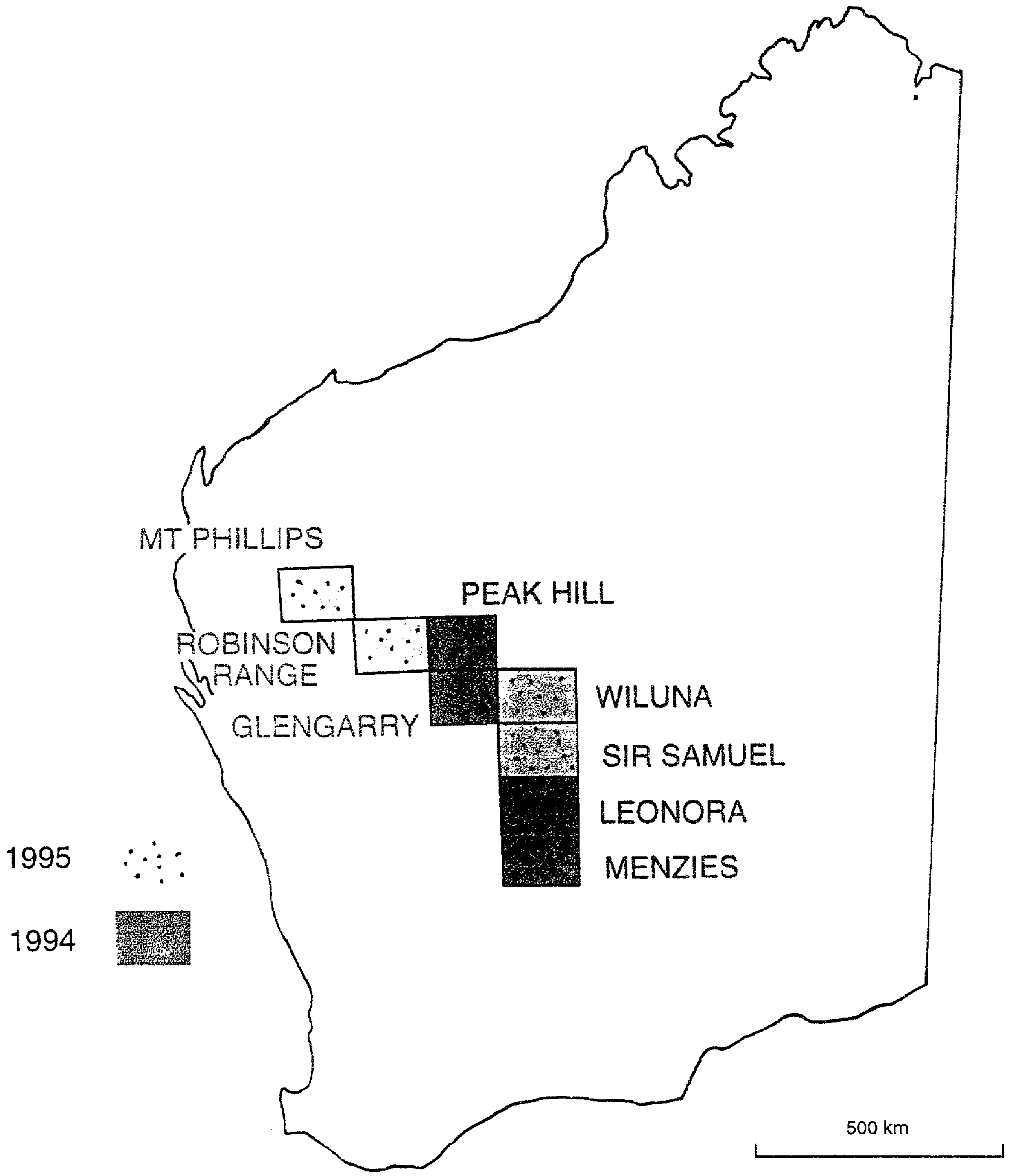


FIGURE 1

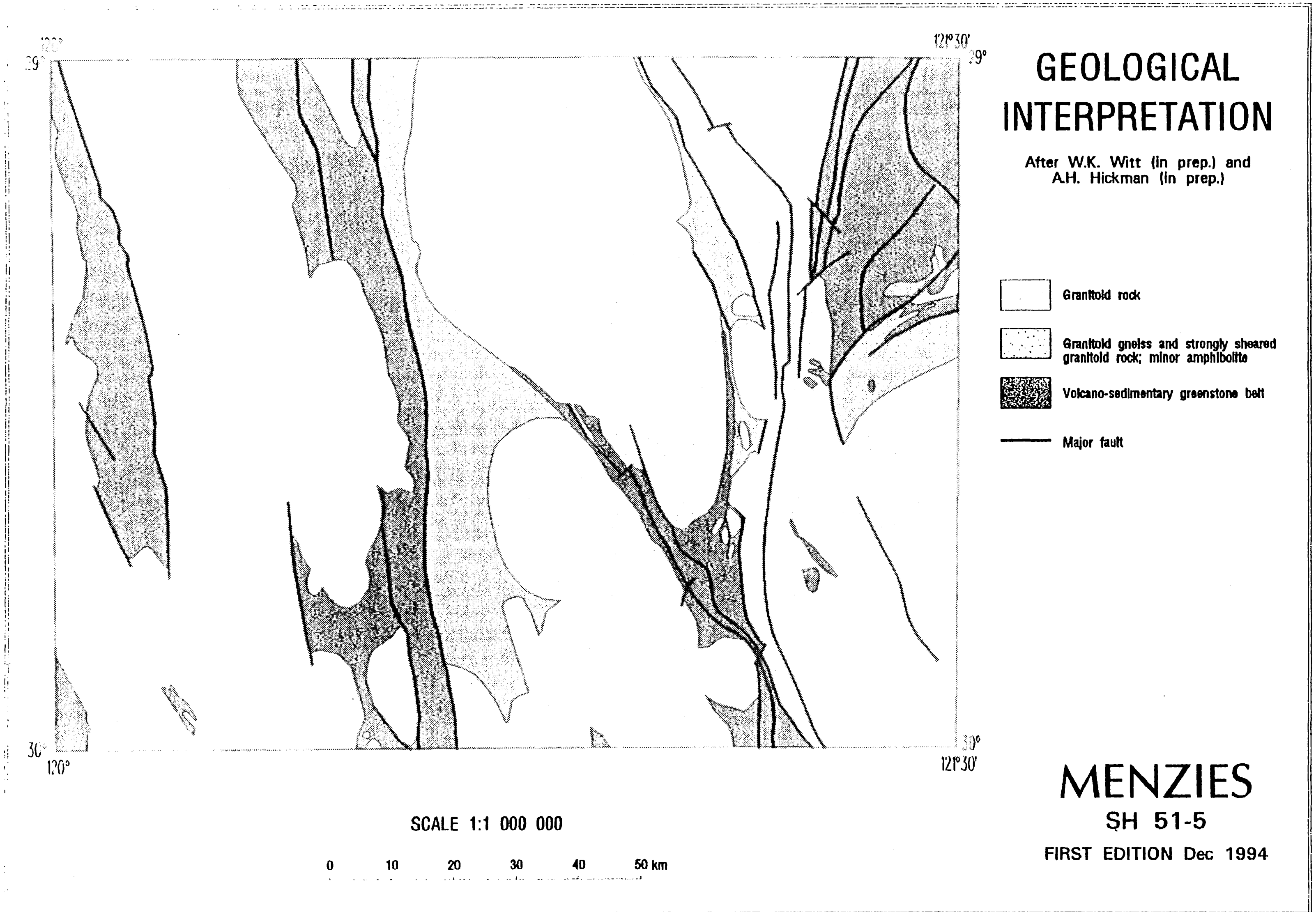

GEOLOGICAL INTERPRETATION
After W.K. Witt (in prep.) and A.H. Hickman (in prep.)
Granitoid rock
Granitoid gneiss and strongly sheared granitoid rock; minor amphibolite
Volcano-sedimentary greenstone belt
Major fault
120°
121°30'
29°
30°
MENZIES
SH 51-5
FIRST EDITION Dec 1994
SCALE 1:1 000 000
0 10 20 30 40 50 km

FIGURE 2

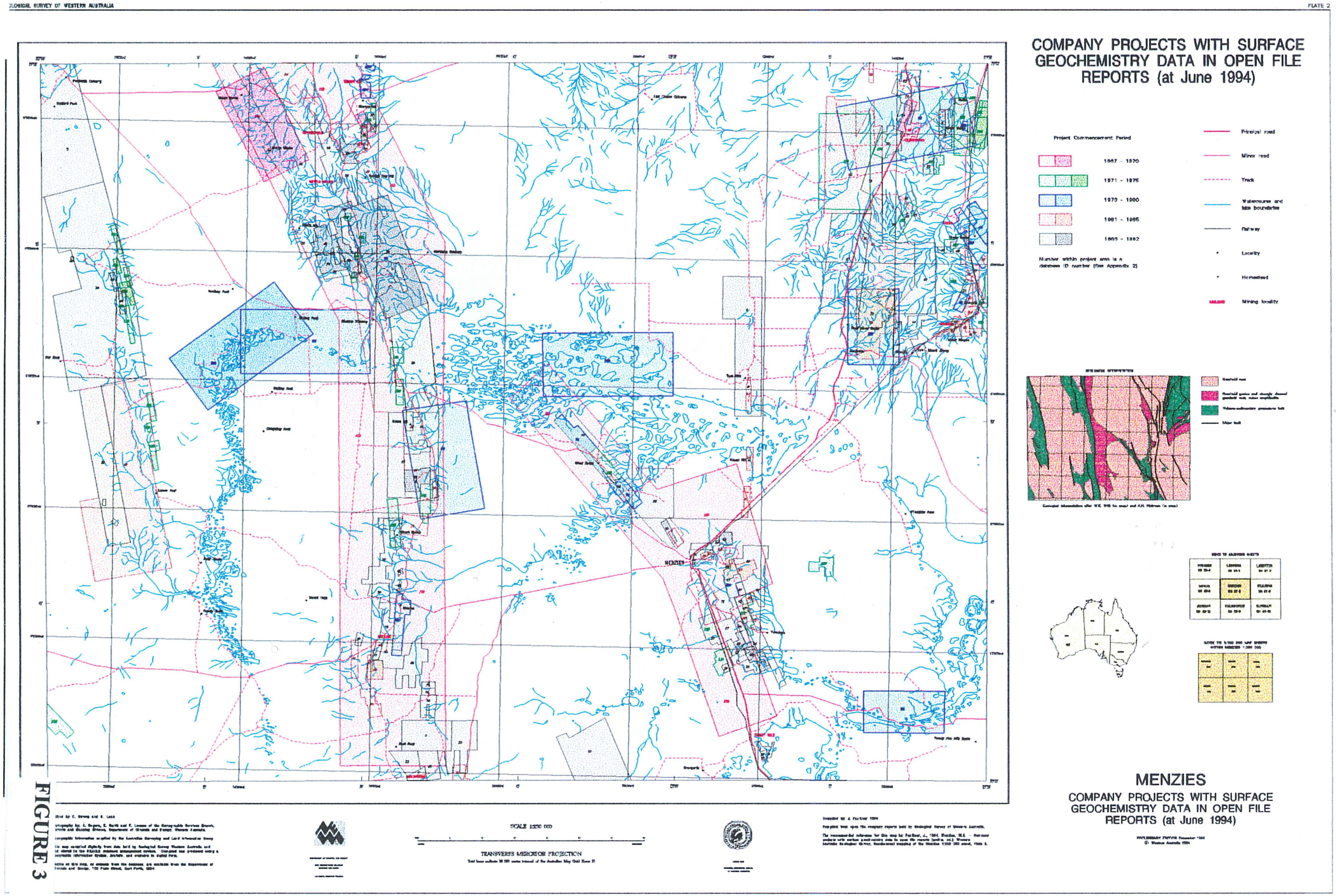


PLATE 2
COMPANY PROJECTS WITH SURFACE GEOCHEMISTRY DATA IN OPEN FILE REPORTS (at June 1994)
Project Commencement Period
1967 - 1970
1971 - 1975
1976 - 1980
1981 - 1985
1986 - 1992
Principal road
Minor road
Track
Watercourse and lake boundaries
Railway
Locality
Homestead
Mining locality
MENZIES
SCALE 1:250 000
TRANSVERSE MERCATOR PROJECTION
MENZIES
COMPANY PROJECTS WITH SURFACE GEOCHEMISTRY DATA IN OPEN FILE REPORTS (at June 1994)

FIGURE 3

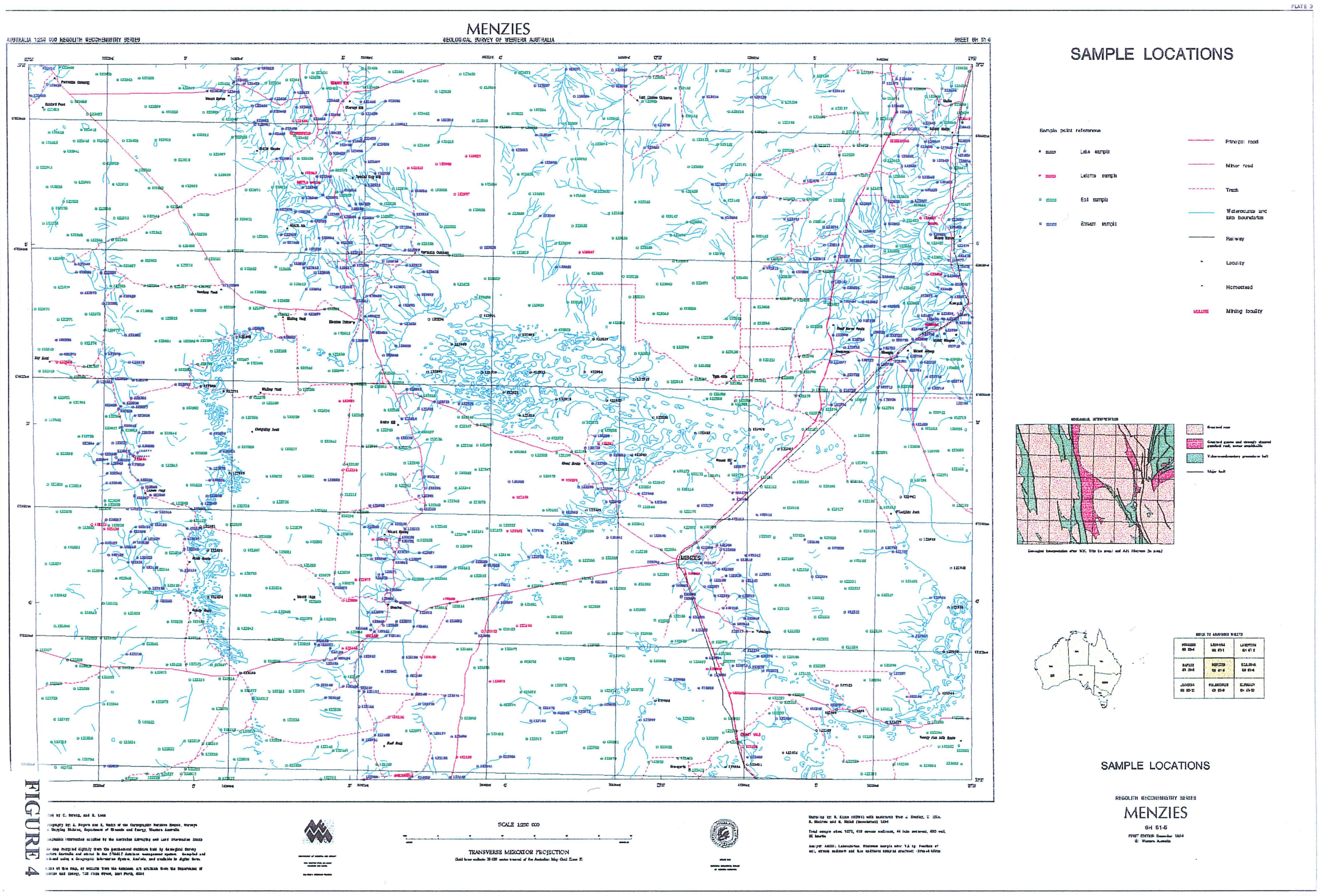
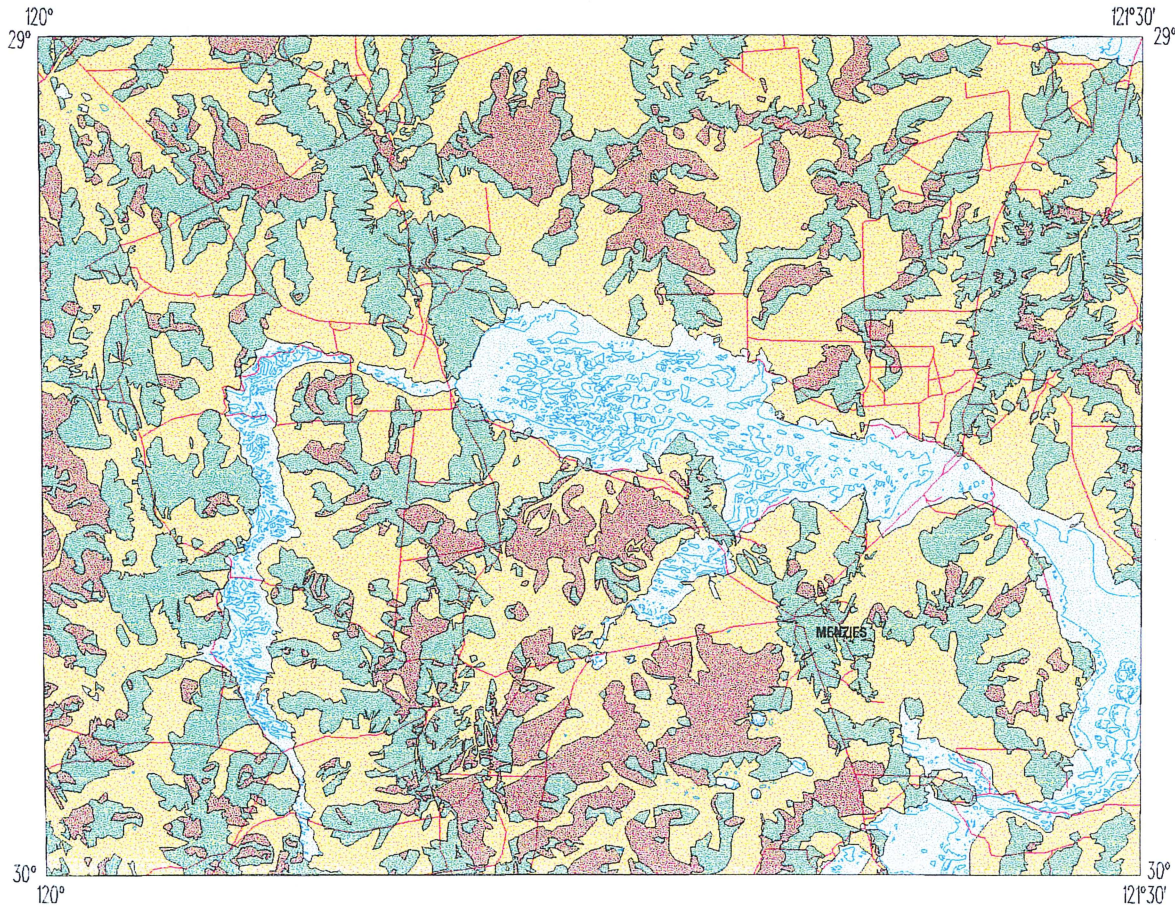

MENZIES
AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
SHEET SH 51-6
SAMPLE LOCATIONS
Sample point reference
Lake sample
Laterite sample
Soil sample
Stream sample
Principal road
Minor road
Track
Watercourse and lake boundaries
Railway
Locality
Homestead
Mining locality
MENZIES
SCALE 1:250 000
TRANSVERSE MERCATOR PROJECTION
SAMPLE LOCATIONS
REGOLITH GEOCHEMISTRY SERIES
MENZIES
SH 51-6
PLATE 3

FIGURE 4

GENERALISED REGOLITH MAP

C. J. Kojan (1994)



Environments

- Relict
- Erosional
- Depositional (non-saline)
- Depositional (saline)

- Lake boundaries
- Roads

MENZIES

SH 51-5

FIRST EDITION Dec 1994

SCALE 1:1 000 000

0 10 20 30 40 50 km

FIGURE 5

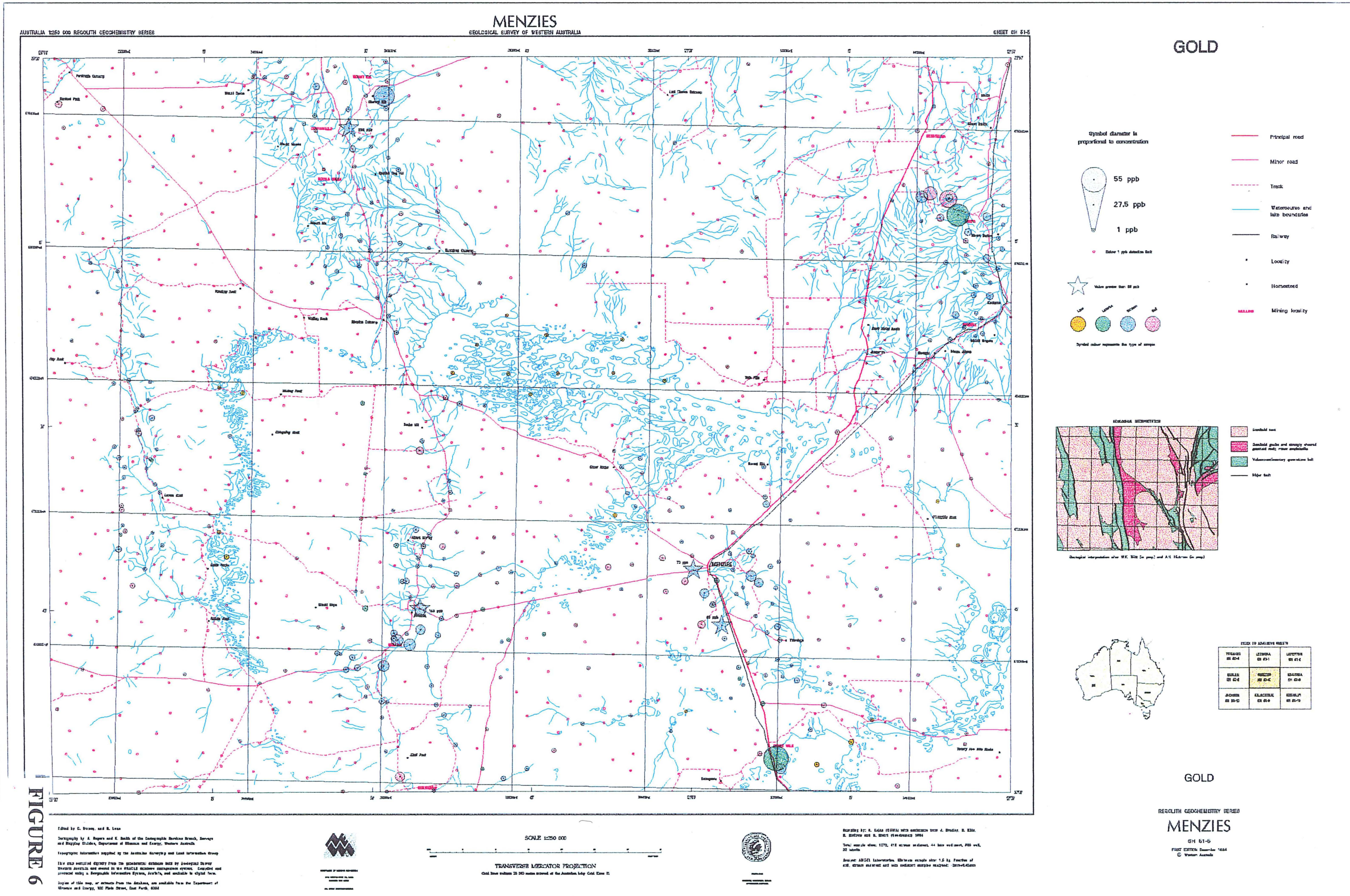

MENZIES
AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GOLD
Symbol diameter is proportional to concentration
55 ppb
27.5 ppb
1 ppb
Principal road
Minor road
Track
Watercourse and lake boundaries
Railway
Locality
Homestead
Mining locality
MENZIES
GOLD
REGOLITH GEOCHEMISTRY SERIES
MENZIES
SH 51-5
SCALE 1:250 000
TRANSVERSE MERCATOR PROJECTION

FIGURE 6

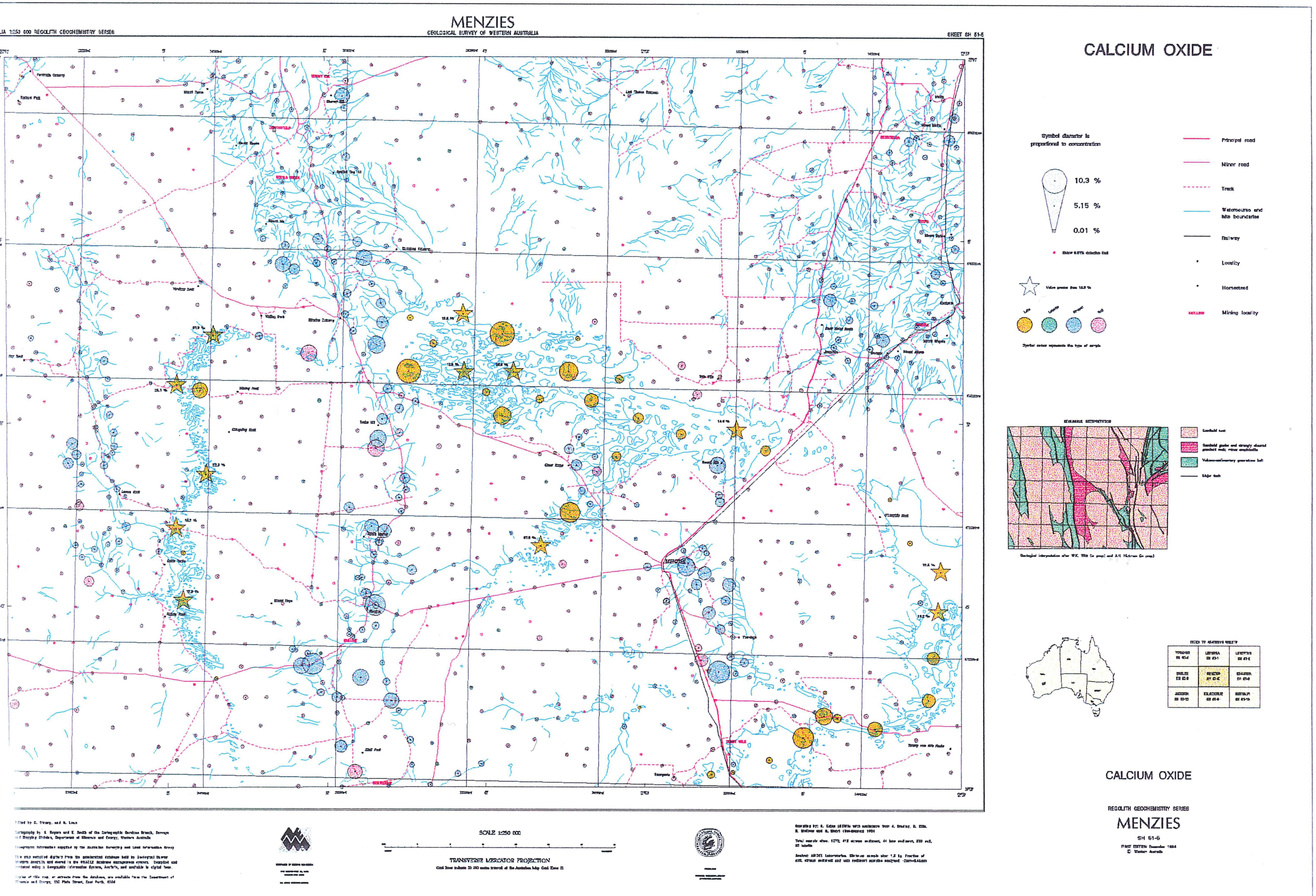

MENZIES
AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
SHEET SH 51-5
CALCIUM OXIDE
Symbol diameter is proportional to concentration
10.3 %
5.15 %
0.01 %
Principal road
Minor road
Track
Watercourse and lake boundaries
Railway
Locality
Homestead
Mining locality
SCALE 1:250 000
TRANSVERSE MERCATOR PROJECTION
CALCIUM OXIDE
REGOLITH GEOCHEMISTRY SERIES
MENZIES
SH 51-5

FIGURE 7

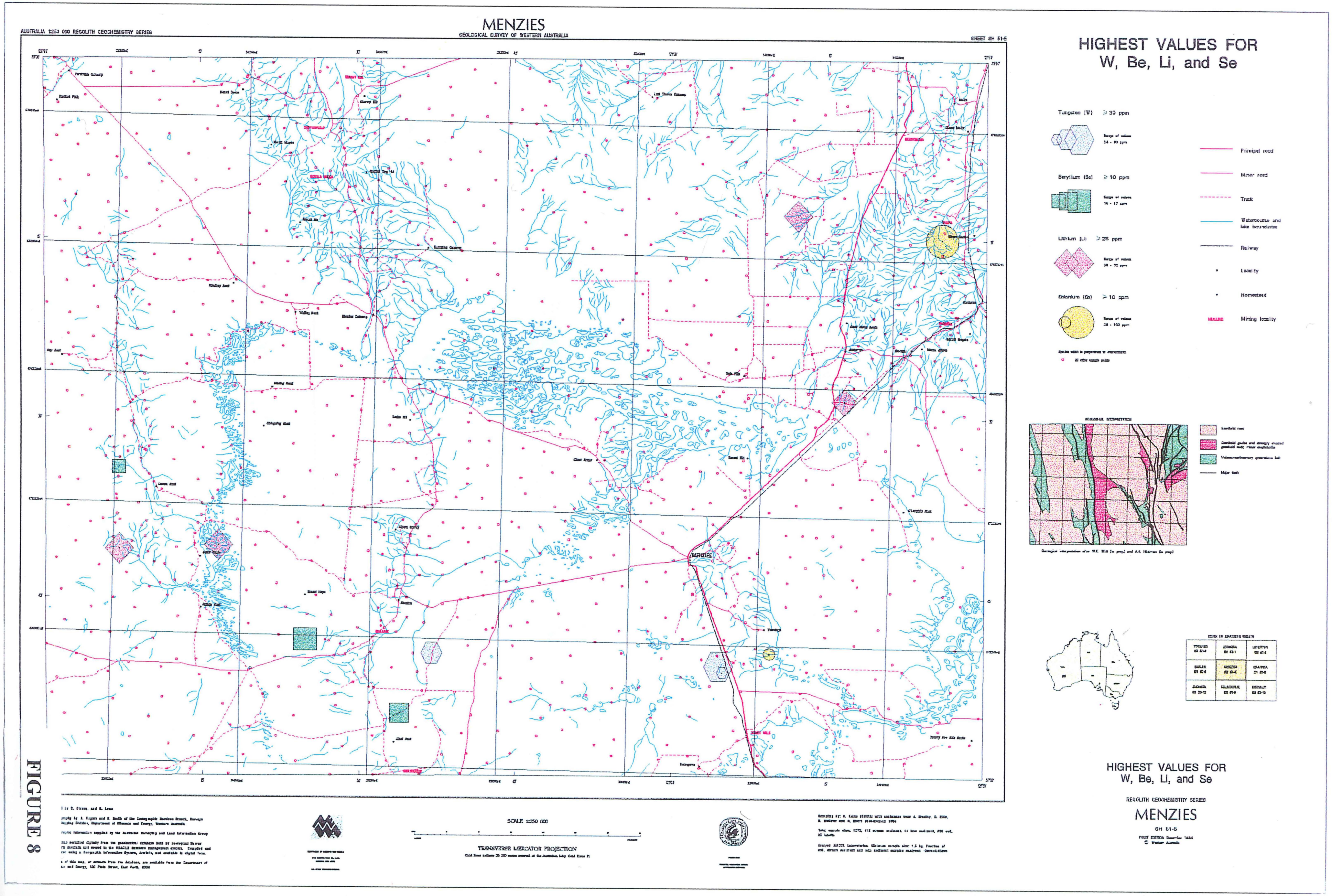
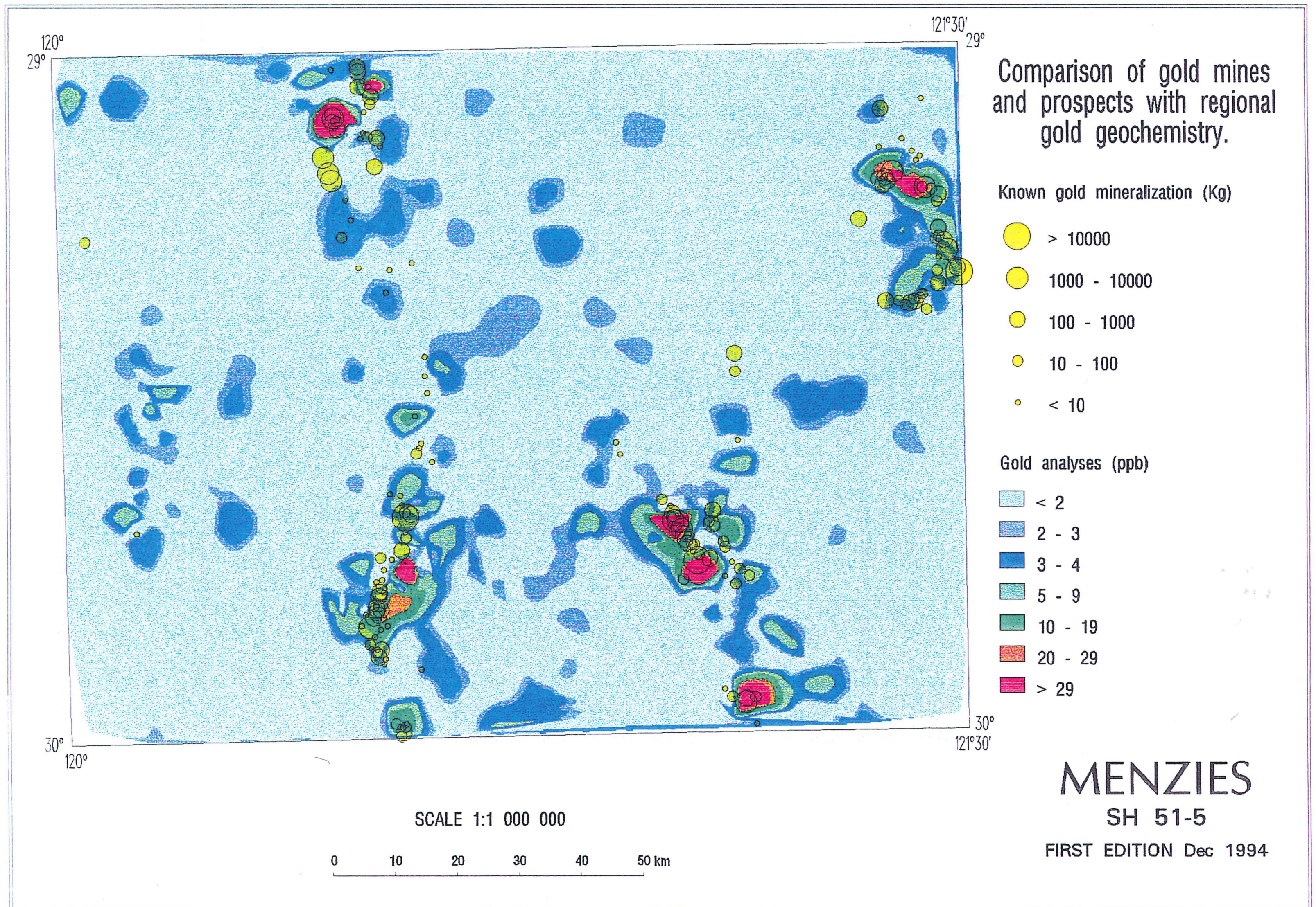

AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES
MENZIES
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
SHEET SH 51-5
HIGHEST VALUES FOR
W, Be, Li, and Se
Tungsten (W) ≥ 30 ppm
Beryllium (Be) ≥ 10 ppm
Lithium (Li) ≥ 25 ppm
Selenium (Se) ≥ 10 ppm
Principal road
Minor road
Track
Watercourse and lake boundaries
Railway
Locality
Homestead
Mining locality
MENZIES
HIGHEST VALUES FOR
W, Be, Li, and Se
REGOLITH GEOCHEMISTRY SERIES
MENZIES
SH 51-5
SCALE 1:250 000
TRANSVERSE MERCATOR PROJECTION

FIGURE 8



Comparison of gold mines and prospects with regional gold geochemistry.
Known gold mineralization (Kg)
> 10000
1000 - 10000
100 - 1000
10 - 100
< 10
Gold analyses (ppb)
< 2
2 - 3
3 - 4
5 - 9
10 - 19
20 - 29
> 29
120°
29°
121°30'
29°
30°
120°
30°
121°30'
SCALE 1:1 000 000
0
10
20
30
40
50 km
MENZIES
SH 51-5
FIRST EDITION Dec 1994

FIGURE 9

MERLIN: A CORPORATE APPROACH TO INFORMATION MANAGEMENT

Geoff Baisden, Principal Graphics Project Officer
Dept Minerals & Energy, Queensland

ABSTRACT: MERLIN is a concept where all non-confidential departmental mineral and energy resource information is accessible through a computerised interface, and easily available in combinations and permutations limited only by the imagination of the inquirer.

A major impact on the way spatial information is managed and used by government agencies and industry has been brought about through the emergence of Geographic Information System (GIS) technology. MERLIN, the system, takes full advantage of this technology by allowing the integration of different data sets through their spatial location and to enable interrogation of associated attribute data to highlight areas of interest.

To allow easy access, MERLIN provides an application specific graphical user interface. All of the functions of the system can be initiated through this interface including data entry, maintenance and interrogation. Output from the system is available in many forms including graphical plots and textual reports.

The Mining Tenures Data Base, Phase 1 of MERLIN, commenced in 1988, is now fully operational statewide in all departmental offices. In continuation of the theme of corporatising departmental information, development of Phase 2 of the MERLIN system, the Geoscience and Resource Data Base, was commenced in mid 1990. Development of this phase was completed in the second half of 1994 and data will be progressively captured through 1995 before being added to the MERLIN system.

MINING TENURES DATA BASE

This system provides assistance in the day to day registering, processing and management of all applications, transactions and dealings for all departmental tenures. Also included is the facility to make available, across the Departmental District Office network, the current position with regard to land availability for mining or exploration purposes.

The system includes data bases containing both spatial and attribute data linked through common keys. These data bases hold information on all Departmental tenures and are held on a central computer housed in Head Office. Each District Office also holds a copy of that part of the data that relates to their area of responsibility. To maintain a currency of data as at the close of business the previous day processes have been developed to update this data overnight. The Mineral Resources Act allows for this disparity by ensuring that most actions do not come into effect until the following day.

Functions have been provided to maintain the data by processing applications, transactions and dealings for all tenure types directly into the system. In respect to application processing these functions solicit both the graphical description and the related administrative details.

The servicing of enquires on the system regarding the availability of land draws directly from this data. Displays can be generated which graphically depict any combination of these data sets together with related attribute information. Textural reports can be generated showing the full administrative details on any tenure type.

The following components have also been included in the system:-

- A Management Information component addresses the potential for delay and will report all actions that are outstanding after an estimated date of completion.
- A Policy and Procedures component has been provided to aid the operator and to maintain consistency of advice in the handling of enquires from applicants. This will enable an operator to access textural information by a keyword search or by a document number.
- Several components of the MTDB address financial processing.

- A Codes and Parameters component has been separately identified to highlight the philosophy of non redundant storage. Lengthy descriptions are stored only once together with a unique code

GEOSCIENCE AND RESOURCE DATA BASE

The Department has for many years maintained a comprehensive range of geoscientific and resource data bases to service the needs of both government and the mineral and energy exploration industries. In the past, these data sets were captured and maintained independently and, if computerised, in many different data base systems.

A review was made of the departmental inventory of data sets to establish their suitability for inclusion in the GRDB. This process identified the following eight suitable candidate data sets.

- Queensland Petroleum Exploration Data Base (QPED) - sub-surface data from company and government drilling
- Regional Mapping Field Data Management System (REGMAP) - site data from Departmental geological mapping projects
- Queensland Mineral Occurrence Data Base (MINOCC) - site data on mineral occurrences
- Aerial Geophysical Surveys of Queensland (AGSQ) - index to company airborne geophysical survey data sets
- Queensland Seismic Surveys (SEISSURV) - index of petroleum exploration seismic surveys
- Queensland Seismic Line Data Base (LINDAT) - index of sections for petroleum exploration seismic survey lines
- Queensland Coal and Oil Shale Data Base (QCOS) - sub-surface data from (mainly) government coal exploration drilling
- Queensland Exploration Reports Index (QERI) - keyworded reference data base to (mainly) company exploration reports

These data sets were modelled into the following GRDB sub-systems -

- Boreholes
- Surface geology
- Seismic Surveys
- Aerial Geophysical Surveys
- Exploration Reports Management System (ERMS)

The following additional sub-systems although not having existing equivalents were also identified for their potential and modelled at this time -

- Soil and Stream Sediments
- Bibliographic References
- Historical Tenures
- Names and Addresses
- Codes and Parameters
- System Environment -
    - Help Maintenance
    - User security
    - User Environment

<u>BOREHOLES</u>

The Borehole Sub-system was developed to enable the storage, graphical display, textual reporting and maintenance of data derived from boreholes drilled in Queensland. In addition the sub-system enables the management of magnetic tapes containing wireline log data and core samples held at the Departmental Exploration Data Centre.

This sub-system replaces the existing Queensland Petroleum Exploration Database, the Petroleum Well Database, the Queensland Coal and Oilshale Database, Coalfile system and the Groundwater Database.

SURFACE GEOLOGY

The Surface Geology Sub-system allows for the capture, display and maintenance of site information derived from observations taken in the field during geological and mineral occurrence mapping activities

This sub-system replaces the existing Queensland Mineral Occurrence Data Base and the Regional Mapping Field Data Management System.

SEISMIC SURVEYS

The Seismic Survey Sub-system provides graphical and summary attribute information for all seismic surveys that have been carried out for petroleum exploration in Queensland. The data contained in this sub-system is derived from information submitted by companies, as well as summarising information contained in company reports lodged with the Department.

This Sub-system replaces the existing Queensland Seismic Surveys Database, Queensland Seismic Line Database and the Shot Point Location Database.

AERIAL GEOPHYSICAL SURVEYS

The Aerial Geophysical Survey Sub-system will provide geographical and summary attribute information for all known aerial geophysical surveys that have been carried out in Queensland. The sub-system will also allow for the management of the archive of data tapes of surveys flown that have been submitted to the Department.

This Sub-system replaces the existing Aerial Geophysical Surveys of Queensland Database.

HISTORICAL TENURES

The Historical Tenures Sub-system will hold the essential details and geographical location for all mining and exploration tenures that have been administered by the Department. In this way an historical record of past mining activity will be held over the entire State. The information to populate this sub-system will be automatically generated by the Mining Tenures Data Base on the termination of a tenure.

The MERLIN system will allow for the graphical display of this information together with a textual report of summary details of each tenure.

EXPLORATION REPORTS MANAGEMENT SYSTEM

It is a requirement under the provisions of the Mineral Resources Act that companies holding Exploration Permits lodge with the Department reports on the results of their exploration activities. These reports are available for viewing in the Department after a confidentiality period.

The Exploration Reports Management System was developed to manage this reporting activity. The system supports the process of receiving, assessing, summarising and retrieval of report data.

The information from this system will be used to update the existing Queensland Exploration Reports Index automatically, by an overnight process, until that database is phased out and replaced by ERMS.

SOIL AND STREAM SEDIMENTS

The Soil and Stream Sediment Sub-system will enable the entry, graphical display, textual reporting and maintenance of geochemical sample and analysis information.

BIBLIOGRAPHIC REFERENCES, NAMES AND ADDRESSES, CODES AND PARAMETERS

These are base level systems of the GRDB. They have been developed to provide a method whereby information entered into the various sub-systems of the GRDB can be validated and entered consistently. Each system consists of a lookup table and enables the entry, maintenance and inquiry of valid entries.

The Bibliographic Reference Sub-system was established to manage the bibliographic references required for all GRDB sub-systems.

A common Names and Addresses Sub-System was identified to allow consistency of the recording of information pertaining to clients across the various sub-systems of the GRDB.

The Codes and Parameters Sub-system contains all of the codes and their descriptions of data that will be entered into the GRDB. Apart from maintaining consistency the use of codes reduces the amount of data entry required if an identical entry already exists.

TECHNICAL DESCRIPTION

SOFTWARE

The proprietary software products ArcInfo and ORACLE were chosen to develop the graphics and non-graphics components respectively. Environmental Systems Research Institute, the developers of the ArcInfo product, have also developed a product that creates a close link between these two products.

Graphical applications software has been written in-house using the ArcInfo macro programming language. This software allows the online querying of land availability and to solicit the information necessary to process the graphic component of a tenure to the appropriate state of acceptance. A user interface utilising pull down menus and screen based forms has also been produced using the same macro language.

Application software written by software consultants and in-house using SQL*Forms, ORACLE's screen based application writer, is used to query, update and maintain the non-graphical data base and are callable from the graphics interface. Other ORACLE software modules used include SQL*Plus, SQL*Report, SQL*Reportwriter and SQL*Net.

A basic requirement of the system was to provide a base map for locational reference. For this purpose, 1500 of the existing cadastral series of maps covering the state at various scales were scanned. These maps are held in simple vector format in a library of 921 tiles conforming to the 1:100 000 sheet system. Also held in this library, on licence from AUSLIG, is their 1:1 000 000 topographic base that has been fully annotated in the Department.

A suitable base on which to display geoscientific data was identified as a requirement for the GRDB. In satisfaction of this requirement, the complete State coverage of 1:250 000 scale geological maps totalling 119 sheets were colour raster scanned and geo-referenced. This base is only suitable for the visual overlay of other data sets included in the system due to the "unintelligent" nature of the images. To overcome this disadvantage, all of the Department's most recent geological mapping has been digitally captured at compilation scale (~1:25 000). This data has been feature coded and forms an "intelligent" map layer in the system. It is planned to expand the coverage of this data set by progressively capturing all new geological mapping data as mapping projects are completed. Additional "intelligent" map layers include the existing State Regional Series maps at 1:500 000 and 1:1 000 000 scale and the Queensland State Geological Map captured at 1:2 500 000 scale.

HARDWARE

The central MERLIN System is housed on a pair of quad processor model 670 Sun Servers. The processor running the Mining Tenures Data Base has 320 megabytes of internal memory while the other, running the geoscientific data base, has 128 megabytes. Each of these servers has 2.6 gigabytes of local disk to hold the Oracle attribute database.

The Department uses a compute server/file server network topology. The file server component of this network consists of a high availability EPOCH-2 infinite storage device. This equipment is based on a Sun 4/75 system with 64 megabytes of memory and 9 gigabytes of local magnetic disk. This disk acts as an active cache for two jukebox optical library units of 30 gigabytes and 57 gigabytes capacity.

Access to the system is via X terminal graphics display devices, PCs running X terminal and VT220 emulation software, Sun Workstations or standard VT220 compatible asynchronous terminals when accessing the text based components only.

These display devices are linked through an Ethernet local area network to the host computer.

Correctly scaled graphical output is available from the system by means of QMS thermal wax colour printers. These devices produce a high quality colour image in a predetermined format of the area displayed on the screen in A3 format. Adhoc requests for graphical output other than the standard format produced by the system are serviced on an "as requested" basis. Pre-formatted textual reports produced from the many sub-systems are output to local laser printers.

SYSTEM STATISTICS

Mining Tenures Data Base

- 521 screen based SQL*Forms applications
- 107 SQL*Plus report programs
- 45 SQL*Report programs
- 142 ORACLE tables
- 4 C programs

Geoscience and Resource Data Base

- 213 screen based SQL*Forms applications
- 90 SQL*Plus report programs
- 21 SQL*Report programs
- 243 ORACLE tables
- 4 C programs

The graphical component consists of :-

- 380 macro language programs
- 172 screen menu programs
- 8 fortran programs
- 39 logical layers of information

CONCLUSION

Through MERLIN the Department of Minerals and Energy now offers a much streamlined tenures management service as well as access to information about past exploration and mining, Queensland's mineral and energy occurrences and resources, and up to date information on the state's geology including maps, boreholes, geophysical surveys and field observations. In the future, this Geographic Information System will be invaluable to the Mining Industry in the development of mining projects.

SPATIAL DATA MANAGEMENT FOR GIS

Colin Farrelly, Computer Services Manager, Australia and Asia,
Exploration Department, BHP Minerals Pty Ltd.

ABSTRACT - Successful exploration and mining in the 1990s depends increasingly on the ability of our geoscientists and engineers to efficiently and effectively acquire, store, manage, analyse and interpret an increasing amount and variety of multi-dimensional spatial information.

Improvements in computer hardware, operating systems and database management software are allowing us to efficiently handle the quantity and complexity of information, while improvements in graphical applications packages are allowing us to effectively analyse and interpret the data.

The increased use of such technology is being driven by increasing requirements to more rapidly find and develop world class deposits. This is despite such deposits being technically more difficult to find in well hidden or inaccessible locations, and being more difficult to develop due to increasing requirements from customers, regulatory authorities and company economic imperatives.

BHP Minerals uses a combination of various data management systems together with interactive graphics software and hardware to handle the large amounts of data required for technical decisions in resource exploration and development. Data management software includes: Oracle, Microsoft Access and a number of systems attached to particular applications packages. The applications software used to analyse and interpret spatial data includes: GIS, statistics packages, image processing systems and 3D visualisation and modelling packages.

Both the business requirements and the emerging technology have lead to a vast increase in the volume of data which needs to be effectively managed and analysed. The spatial context of the data has come to dominate both the management and analysis of most of our large data sets.

Database Management is seen as a distinct process between data acquisition and data analysis, and it usually occupies most of the effort in the computer processing of the data. The use of a variety of different packages to meet any given technical objective is now common, and it has lead to an increased emphasis on the methods of data conversion. Improvements in standard methods of data transfer and the direct attachment of databases to applications packages is greatly increasing our ability to use the right software for the right job.

The trend for some time has been towards third party database and applications software, although there is still a significant amount of work required to build database applications and to integrate the database with graphical applications systems. This development process continues to be a challenge to ensure that large systems can be built effectively to suit the user requirements with a minimum amount of redevelopment.

The model for the optimum management of spatial data varies according to the specific requirements, but the trend is towards decentralised project databases on PC platforms which can link to centralised strategic systems on a Unix platform.

Both the relational and the graphical approach to handling spatial data results in faster and better methods of data validation and data analysis. When coupled with real-time interactive methods of GIS visualisation and modelling, it facilitates decisions which are more informed, more timely and more easily sold to management.

The trends over recent years are clear, and such methods are quickly becoming a normal part of every stage of the exploration and mining process.

BUSINESS DRIVERS

- ***Growth Objectives***

  - Desire to grow at a faster rate.
  - Need to acquire large low cost deposits.
  - Most effective to find and develop our own.
  - Need to improve efficiency.

- ***Harder Targets***

  - Easy ones are already mines.
  - Remaining are well hidden or inaccessible.
  - Lowest cost extraction and processing requires more information and more detailed feasibility work.

- ***Increased Requirements***

  - Customers have more stringent requirements (quality).
  - Designs now need to be optimised - this requires data.
  - Higher hurdles set by the regulatory authorities.
  - Company needs to quantify and reduce risk by analysis of more options.

TECHNOLOGY ENABLERS

- ***Hardware***

  - Processing power (doubles every 18 months and shrinks in size).
  - Memory advances (doubles every 18 months).
  - Small format high speed large capacity disks.
  - High speed, high resolution graphics screens.
  - High resolution colour plotters and printers.
  - Hardware costs remain stationary while performance increase.

- ***Software***

  - Software developed to take advantage of the hardware.
  - Graphical user interfaces have become the norm.
  - Trend to graphical processing interaction and display.
  - Flexibility in operation to allow the user to tailor.
  - Third party software preferred over inhouse development.
  - No one package can do everything.

- ***Data***

  - Data captured once, in digital form, near to its source.
  - Data acquisition - new industry in trading data.
  - Data validation at time of capture or soon after.
  - Decreased emphasis on data entry.
  - Increased emphasis on data conversion.

DATABASE MANAGEMENT SOFTWARE
In use at BHP Minerals Exploration, Australia

- **Relational DBMS**
  - Oracle (rev 6 to rev 7, Unix)
  - MS Access (ver 1 to ver 2, Windows & Unix)
- **Text DBMS**
  - Techlib/Basis (ver 3, Unix)
  - In-Magic Plus (ver 1, Windows)
- **GIS and Image Processing DBMS**
  - Arc/Info (ver 7, Unix)
  - Intrepid (ver 3, Unix)
- **Three Dimensional DBMS**
  - Techbase (ver 3, DOS)
- **CAD design/drafting data**
  - Microstation (ver 4 to ver 5, Dos to Windows)
  - CorrelDraw (ver 4 to ver 5, Windows)

INTERACTIVE GRAPHICS APPLICATIONS SOFTWARE
In use at BHP Minerals Exploration, Australia

- **Geographic Information Systems (GIS)**
  - Arc/Info (rev 7, Unix)
  - ArcView (ver 2, Windows & Unix)
- **Image Processing Systems**
  - Intrepid (ver 3, Unix)
  - ER Mapper (ver 4, Unix)
- **Statistics Packages**
  - Datadesk, Statview, SAS/JMP (Apple Mac)
  - SPSS (ver 6, Windows)
  - S-Plus (ver 3, Unix)
- **3D Visualisation and modelling packages**
  - Easimine (ver 2, Unix)
  - Explorer (ver 2, Unix)
  - VoxelGeo (ver 2, Unix)

INCREASED DATA VOLUMES

- **Advanced Techniques Create More Data.**
  - Trend of increasing data volumes in traditional data sets (eg. satellite and airborne remote sensing techniques are geometrically increasing data volumes to improve resolution).

  - Improvements in measurement technology creates more channels of information, faster (eg. digital climate monitoring, ICP chemical analysis).

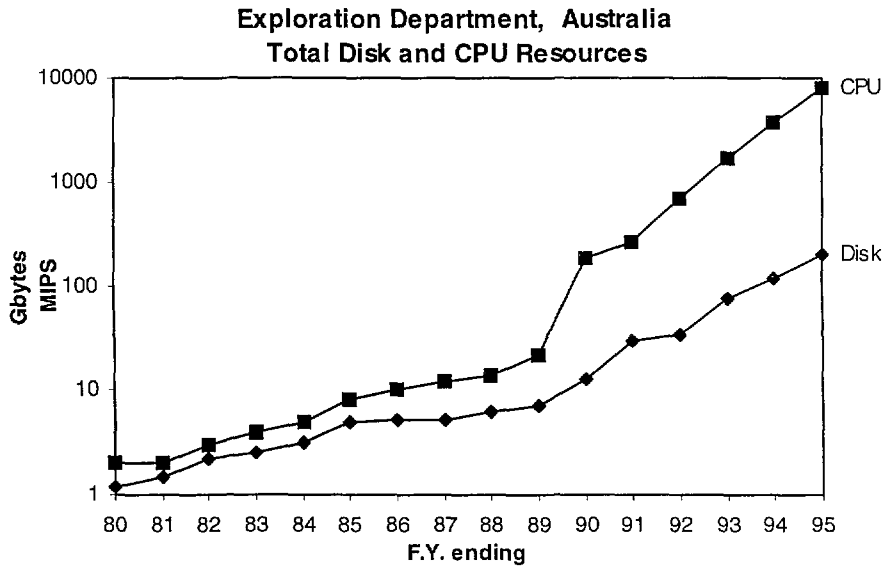
- **Increasing Availability of Data**
  - Decreasing costs of data capture create an opportunity to collect more.
  - Digital capture methods automatically create more data than is normally required (eg. radiometrics, climate).
  - Government and third party suppliers are making large amounts of data available cheaply.

- **Greater Capacity to Store and Manage Data**
  - Disk and tape storage capacity is rapidly increasing and costs are decreasing.
  - Price performance of computers is also allowing the data to be more efficiently processed.
  - GIS and relational databases are improving our ability to properly manage the volumes of data.
  - Examples. Exploration disk capacity chart. Development databases:
    Iron Duke 1985 was 20MB, Cannington 1994 is 10GB.

- **Opportunity for More Analysis**
  - More can be done with more detailed data and more dimensions of data.
  - More needs to be done to effectively integrate and interpret such volumes of data.

INCREASED DATA VOLUMES

- **Disk Usage in Minerals Exploration.**



- The relatively rapid increase experienced in the early 1980s was mainly due to the increased use of satellite and airborne geophysical remote sensing data. This increase of around 1 gigabyte per year was considered to be unsustainable at the time, although in recent times, increases of 40 GB per year are considered normal and manageable.

- The growth in disk capacity has been more than matched by a growth in computer processing capacity (as measured in millions of instructions per second CPU capacity). The acceleration experienced since 1990 corresponds to the migration from Data General mini-computers to unix workstations and servers, as well as to the rapid proliferation of PCs.

DATA MANAGEMENT

- **Definition of a Database**

    - *"... a collection of interrelated data stored together without harmful or unnecessary redundancy to serve multiple applications; the data is stored independent of programs which use the data; a common and controlled approach is used when accessing data held within the database."*

      James Martin

    - Database Management is a distinct process between the acquisition and analysis of the data. Care needs to be taken, since this stage involves most of the effort in the computer processing of the data.

    - It is now widely accepted that it is necessary to use a variety of different packages to meet any given technical objective.

    - This has lead to an increased emphasis on the methods of data conversion, with improvements in standard methods of data transfer and with the direct attachment of databases to applications packages.

Data Flow Diagram

DATA CONVERSION

- **Requirements**
    - Must be simple and easy.
    - Must be quick and efficient.
    - Must be reliable.
    - Must be standardised.

- **Priorities** *(in decreasing order of importance)*
    - Structure (tables, fields)
    - Dictionary (names, code lists)
    - Format (ascii, binary)
    - Medium (tape, disk)

- **Examples**

1980 Seismic Weathering Corrections
- Field desktop computer to floppy disk.
- Mail to office and upload to Data General mini-computer.
- Dial-up and download to Phillips cassette tape.
- Copy to punch cards and submit to CDC mainframe.

1985 Geochemical Data Transfer
- Sample results entered at laboratory.
- Copy to either magnetic tape, floppy disk or via modem transfer.
- Upload the defacto standard ascii files to GEM plotting system.
- Attempt to standardise to a more involved AMIRA format fails.

1990 Drillhole Data Processing
- Barcode logging onto field handheld or laptop computer.
- Floppy sent to office and uploaded to Oracle database.
- Extract into standard BHP DDF ascii files.
- Upload into Easimine or Datamine or Techbase for plotting.

1995 Field Sample Collection
- GPS reading of coordinates into PC database.
- Barcode reading of sample tag into PC database.
- Plot locations using GIS attached to database.

TRENDS IN DATA MANAGEMENT (at BHP Minerals, Exploration)

• Data Complexity and Database Evolution

- There has been an increase in the complexity of data being stored and a concurrent evolution of methods of data management systems.

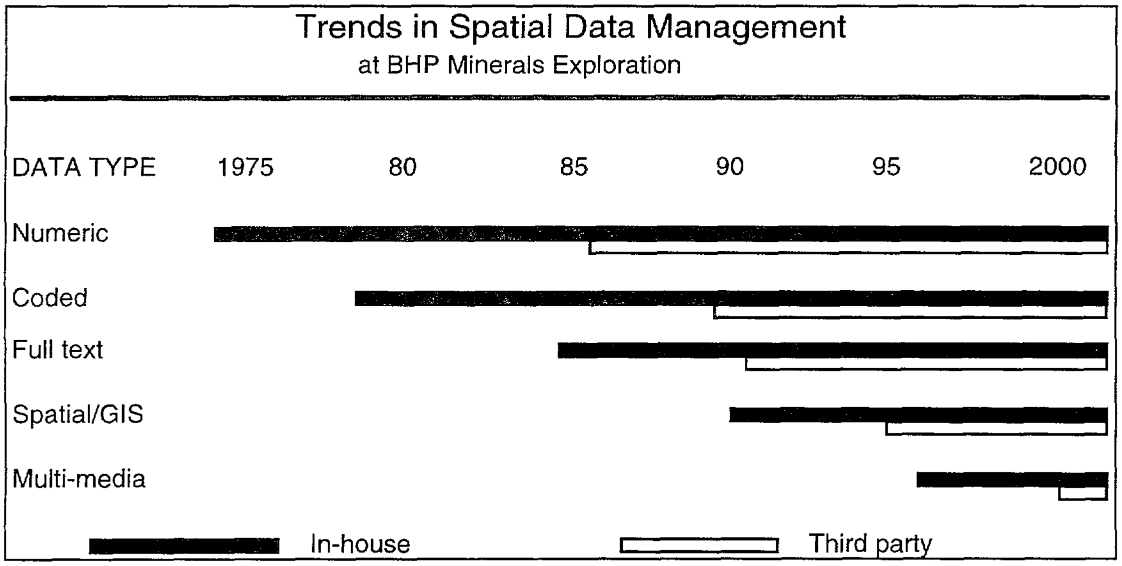
- Originally, only numerical data was stored, often in hierarchical and inflexible databases.

- Coded fields then became the simplest method of providing searchable textural information. A number of in-house systems were written around the indexed sequential access method (ISAM) or else around a rudimentary relational model.

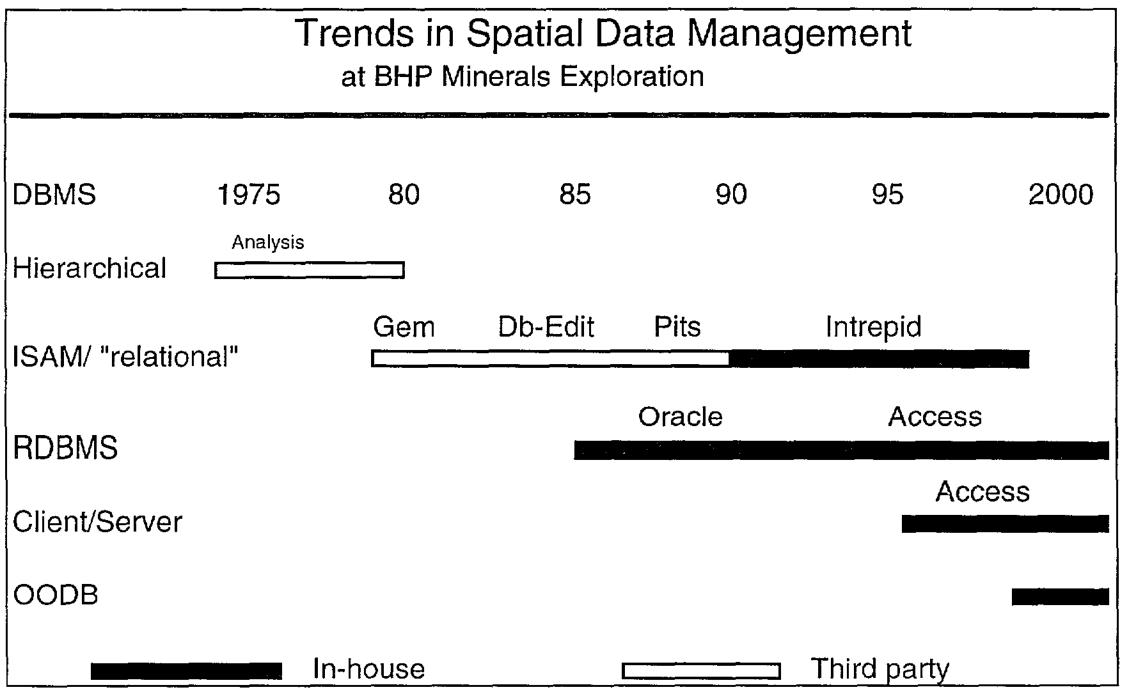
- The advent on third-party relational database management systems (RDBMS) allowed for free text information which could be easily stored and searched along with numerical and coded information.

- The proliferation of graphical plotting and viewing applications in recent years has lead to an increasing requirement to store and manage spatial information.

- The next phase will be characterised by the increasing use of client server systems and object-oriented databases (OODB). The data stored will also include multi-media information such as voice data, images and moving pictures.



- **Spatial and Attribute Data Management**
  - There has been a shift in software technology which allows for the integration of spatial and attribute data.
  - GIS and Image Processing systems focus the data management on the spatial context of the data.
  - Attribute information can still be stored separately in relational databases and other file formats and then linked to the spatial information.
  - Spatial location becomes the primary means of integrating different data sets.
  - Different types of analysis become possible by focusing on the spatial context of information.



MAJOR SPATIAL DATABASES
(at BHP Minerals, Exploration)

- **Data-based Resource and Exploration Geology System (DREGS)**
  - Project based system for management of detailed logging and assay data for drillholes.
  - Simple table structure with a fixed 'core' structure, to which different fields and coding systems can be added for each project.
  - Separate versions running on Oracle in each office in Australia.

- **Drillhole Reconnaissance Database (DRLRECON)**
  - Summary database for regional data compilation.
  - Simple fixed table structure with no modifications allowed.
  - Flexible enough to allow recording of any relevant data via user defined 'parameters'.

- **Techlib Bibliographic Database (REPORT)**
  - Centralised reference database containing detailed descriptive and keyword information about all company reports.
  - Spatial locations recorded by reference to tenements, mapsheets, tectonic units or arbitrary polygons. A resulting GIS coverage can be spatially searched.
  - Techlib system is built on the BASIS database, which allows for the efficient management and searching of free text and keyword sequences. A detailed thesaurus can be referenced using abbreviations and aliases.

- **Geochemical Database (GEOCHEM)**
  - Centralised Oracle database for the management of surface and subcrop geochemical data.
  - Suitable for both project data and for regional data compilation.
  - Fixed data structure with flexibility to store any relevant information, with procedures to simplify data upload, data entry and data extraction.
  - Relational design with each sample determination on a separate record. The system runs surprisingly well given that 600,000 samples are currently stored with a total of 3,000,000 determinations.

- **Mineral Occurrence and Deposit Database (DEPOSIT)**
  - Centralised Oracle database for the compilation of summary information about mineral occurrences and deposits.

- A Microsoft Access version has also been written to run independently on a PC, and to act as a GUI to the Oracle version.

- Source information can come from a variety of external databases and from internal compilations.

- Fixed but flexible relational data structure as for the Geochem database. Can store descriptive geological information as well as reserve and production data.

- Currently stores details on 300,000 occurrences and deposits.

• **Global Data Index (GDI)**

- Decentralised Access PC database for the compilation of summary information about datasets ("database of databases").

- Fixed but flexible relational data structure as for the Geochem and Deposit databases.

- Can store and query descriptive information, keywords and spatial locations.

- Intention is for it to act as a data asset register for each office worldwide, which can be periodically merged to a central copy and redistributed.

DATA ANALYSIS

• **Stages of Maturity for Data Analysis**

1. Collect, enter and store the data.
   (Relational databases)
2. Reproduce the data in a form similar to its original.
   (Reports, CAD drawings)
3. Enhance the data to demonstrate features from the data.
   (Mapping and imaging systems)
4. Create and analyse new and derived data to exhibit features not immediately obvious in the original data.
   (3D Visualisation and Modelling systems)
5. Integrate and analyse all datasets from varying sources.
   (Geographic Information Systems)

CURRENT LIMITATIONS

- Islands of data produced by vendor specific database design leading to data conversion and compatibility issues. Problem made worse by lack of reliable data transfer standards.
- Different software approaches to spatial data management and analysis (eg. raster image processing systems versus vector CAD and GIS; 2D versus 3D systems)
- Scalability and portability problems across hardware platforms and across different operating systems.

- Training and education - the limitations of the Science and Engineering undergraduate programmes at Australian Universities.
- Network capacity - both local and wide area.

THE FUTURE

- Data integration - common formats and methods of connectivity.
- Systems integration - convergence of DB, GIS, Imaging and 3D systems.
- Increased public availability of data and improved data capture methods.
- Continued rapid improvement in graphics hardware and GUI software.
- Less reliance on specialist practitioners.
- Portable systems and remote access to data.
- Real time graphics generation, interaction and modelling.
- Multimedia data manageable and useful.

Exploration data management on a mineral province scale

Simon D. Beams
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Since the late 1960s, mineral exploration programs have to a large extent covered the exposed portions of the basement geology of Australia's mineral provinces with surface sampling. In more recent times, extensive drilling programs have also investigated the covered areas adjacent to the basement blocks.

All these exploration data eventually come into the public domain, because Australia (unlike many other countries) is blessed with a mining law where this is a requirement of title. The Open File system, which releases the results of previous exploration activities, is no doubt one of the contributory factors to the enviable mineral deposit discovery rate in Australia. However, as the volume of material held in Open File records rapidly expands, the ability to interrogate efficiently by manual methods this valuable, but grossly fragmented, data source, is fast becoming impossible: Almost all of these data are still trapped as hard copy reports, on uncontrolled maps or on outdated technology such as microfiche.

Our estimate is that in the three mineral provinces of North Queensland that Terra Search has had most involvement with, the Mt Isa Inlier, Ravenswood Block and Drummond Basin, there are approximately 200 000 stream sediment samples, 400 000 soil samples, 150 000 rock chip samples and well in excess of 500 000 drillhole samples. Similar sample numbers would apply to other mineral provinces around the country. Until recently this great resource has been locked in a time warp, totally inadequate in its current form, for analysis by state of the art geoscientific information systems (GIS).

Although some major companies are compiling proprietary data sets, historical information is accumulating at a much greater rate than previously. Government agencies are custodians of geoscientific data, but they do not have the hands-on exploration experience, nor have they allocated serious funding to compile the historical open file data into a digital data base. Since the early 1980s, we have the rather bizarre situation that all geochemical data has left assay laboratories in digital form, but virtually no digital geochemical data has reached the open file system.

However, we can now say that we have the technology to improve this underutilization of available data.

The three elements required are:

1) a structured data management system which has to be in place to accept multifaceted new and historical exploration data.

2) geographical information and map-making systems to visualise the data. There are many packages in existence that can achieve this - all they need is good quality, accurately located data.

3) the willingness to wade through the mountain of historical reports to glean the critical data. A good working knowledge of the industry and rigorous persistence is required to successfully produce a standardised data set.

These three elements have in fact come together in North Queensland, for example, in the Mt Isa Block, AMIRA Project P413 on the optimisation of open file data is nearing completion, having realised many of its original objectives. This project is supported by 14 major exploration and mining houses and the Queensland Department of Minerals & Energy. Other major data compilations cover the Ravenswood Block and Drummond Basin.

Terra Search have researched and developed the EXPLORER II Data Management System, which utilises the power of a structured relational database, to capture, record, interrogate and visualise exploration data gleaned from historical reports (Beams, 1994). The first step in the process is the painstaking transfer of samples from uncontrolled hard copy maps to controlled drainage bases and subsequent digitising with AMG coordinates. After conversion to digital form, each sample sits in an interconnected framework accompanied by its essential attributes such as location information, sample collection methods, analytical techniques, assay data, with cross links into existing geoscientific and geographic data bases: eg. drainage bases, tenement information, regional geophysics. Examples of the relational cross links are given in Figures 1 and 2. With drill holes, information such as bedrock lithology, depth of transported cover, pyrite content are all stored and available for interpretation - see Figure 3.

A comprehensive geochemical data set has been built up for several mineral provinces, for example the Ravenswood Block and Drummond Basin regions. To date this set consists of 36 000 stream sediment, 20 000 rock chip, 80 000 soil, and 66 000 drill hole samples. Figure 4 illustrates this sample coverage in terms of 44 000 plus stream sediment samples analysed for bulk cyanide leach extractable gold in stream sediments (BCL's).

The Mt Isa data base currently stands at approximately 75 600 stream sediment, 16 300 rock chip, 55 000 soil, 27 600 drillhole samples; the latter coming from approximately 9 200 drillholes. Figure 5 is a plot of sieved stream sediment locations and gives an indication of the extent of the regional data currently residing in the data base. Figure 6 shows a subset of this data which plots only those samples analysed for Au by BCL or other methods.

Each one of these thousands of points is able to be queried and visualised on the basis of a host of attributes; eg. element content, sampling method, tenement (EPM) number, Company Report (CR) number, date and technique of analysis, geological unit.

The primary advantage of systematic data compilation such as this, is that the data is now available for analysis and visualization with application programs in a GIS environment. When this occurs, the geologist end user is in a strong position to take full advantage of the data, to establish trends in previously collected samples or historical surveys and integrate these with their own current project data.

As an example, it is easy to subset the data to show all samples in relation to a particular unit eg. the Lawn Hill Formation, then either carry out basic statistical analysis, print out, or plot this sub-population. Alternatively comparisons can be made between BCL samples collected with particular mesh sizes (eg. -20# compared to -9#) or those analysed by particular assay methods (eg. static compared to active leach).

The involvement of the Queensland Department of Minerals & Energy (QDME) has been pivotal, as it has allowed direct integration of the geochemical and geological data with the open file company report system, historical mineral tenement data and geological mapping. Figure 7 is an example of how the historical tenement layer can be interrogated and utilised with other geographical/geological layers. In this instance EPMs 1000 to 2000 have been selected and subsetted. Information such as CR#, date terminated, and title holder are all searchable.

In the not too distant future, geochemical and drillhole data required for statutory technical reports are likely to be requested from the tenement holder in digital format. Collaborative studies by the QDME and Terra Search have shown that relational data bases such as EXPLORER II would be suitable mechanisms for such data storage and transfer.

In the interests of efficient mineral exploration, it is imperative that historical and future exploration data is properly recorded and fully utilised. This requirement is accentuated by the increasing application of sampling procedures emanating from the Yilgarn Block, where CSIRO and AMIRA sponsored research has lead to a greater understanding of the regolith and utilisation of innovative sampling media in mineral exploration (see Anand and Smith, 1993).

Innovative developments such as partial extraction analysis (eg. BCL) or selective sampling media (eg. lateritic pisolites) have meant that raw assay numbers may no longer be directly comparable. Incorrect interpretations based on spurious comparisons are likely, if vital attributes on assay techniques and sampling methods are not recorded with assay data and accessible in a structured data management environment.

Thus, as mineral exploration in the Mt Isa Inlier moves into the next phase of the digital age, it is important to recognise that careful documentation of sample collection methods, analytical procedures and accurate sample location will be as essential in the future as it should have been in the past.

When these exploration data are combined with the other geoscientific data available, such as digital geology, Mineral Occurrence data, multiclient aeromagnetics, TM, Bulk Rock geochemistry, explorers over these mineral provinces will then have tremendously effective multi-layered data sets available to facilitate discoveries.

References:

Anand, R.R. and Smith, R.E., 1993. Regolith distribution, stratigraphy and evolution in the Yilgarn Craton - implications for exploration. In: An International Conference on Crustal evolution, metallogeny and exploration of the Eastern Goldfields (Eds. P.R. Williams and J.A. Haldane). Extended Abstracts. AGSO Record 1993/54

Beams, S.D., 1994. Recent developments in the management of exploration data from North Queensland. In: New Developments in Geology and Metallogeny: Northern Tasman Orogenic Zone (Eds. R.A. Henderson and B.K. Davis), pp. 23-26 EGRU Contribution 50, James Cook University, Townsville.

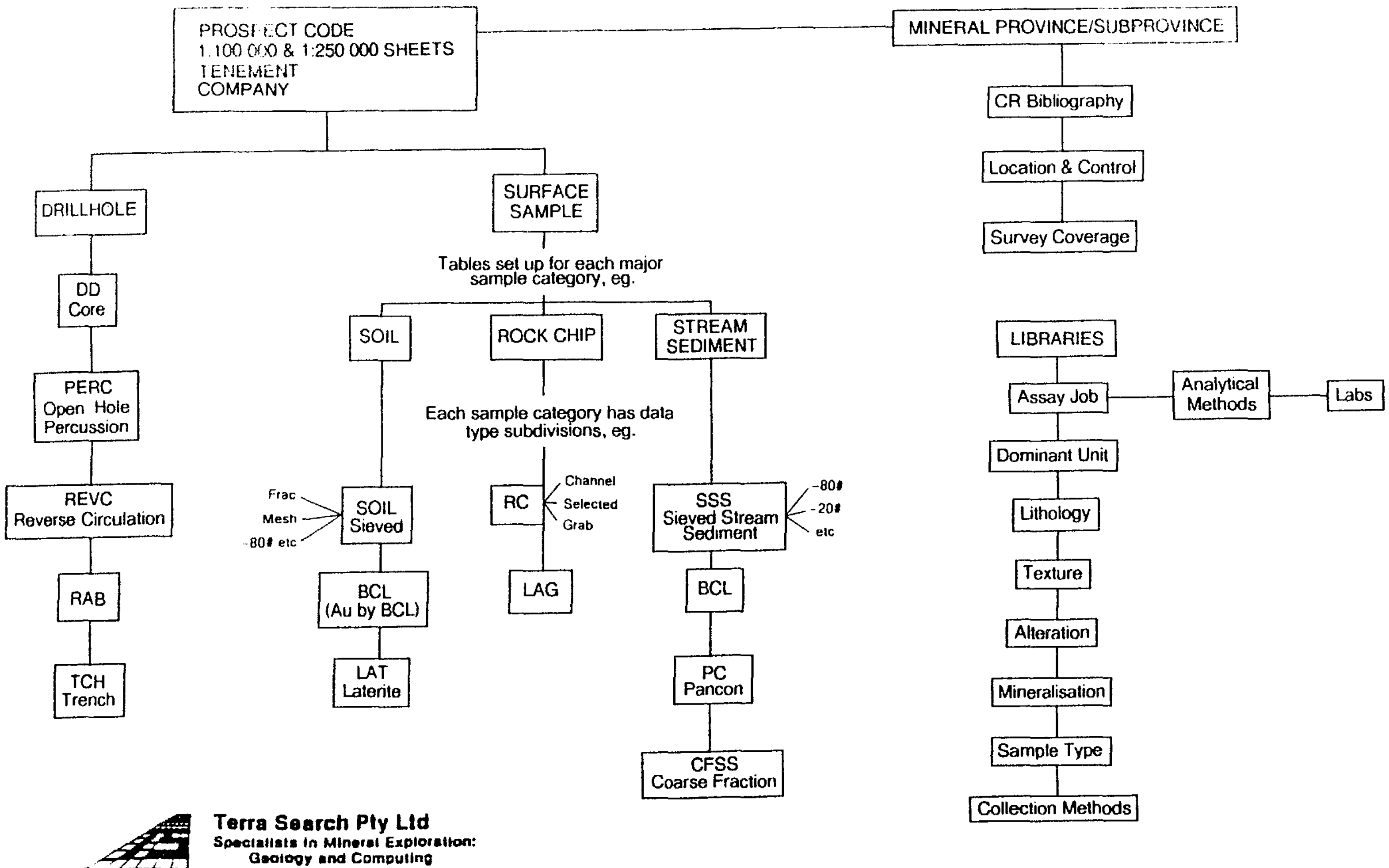

Figure 1

EXPLORER II.1 DATA BASE MANAGEMENT
Organisational Schema for Major Information Categories

17/02/94 **TERRA SEARCH PTY. LTD. TOWNSVILLE - Explorer-II**

Decoded Rock Chip Ledger Report
Mount Isa Open File
Lake Gregory-Top Camp Prospect

SAMPLE : **17509**

Prospect : **LGTC** : Top Camp (Lake Gregory)
100k sheet : **6955** : Malbon
AMG N: 7670554 Local N:
AMG E: 440154 Local E:

Locality : Top Camp-Black Fort Fault Zone
Data type : Rock Chip sample
Dominant Unit : Overhang Jaspilite
Occurrence :Outcrop Method :Continuous Channel - 1.00 m
Sample Type :Alteration Zone

Photo Ref. : Run : Frame : :

Lode : Width : 4.00 m Length: 250.00 m
Strike: 40.0 deg. Dip : deg. Dir :

Lithology :
(SST)Sandstone
(QVN)Quartz Vein

Texture :
(STV)Stockwork Veining

Alteration :
Strong Sericite
Strong Silica

Mineralisation :
Vein 2% - 5% Quartz

Sulphide Content :

Assay Job details
Job Date : 1/3/89 Company Report #: 21072
Laboratory : Pilbara Laboratories AtoP/EPM : 3917

ELEMENT	UNITS	DET.LIMIT	PREPARATION & ANALYTICAL TECHNIQUE
Au	ppm	0.005	crush,weigh with flux (W/FLUX) 50g fire assay/Pb collection/AAS finish (313)
Au repeat	ppm	0.005	crush,weigh with flux (W/FLUX) 50g fire assay/Pb collection/AAS finish (313)
Cu	ppm	2	Dry,crush,split,pulverise (DCSP) Perchloric acid digest AAS finish (101)
Pb	ppm	5	Dry,crush,split,pulverise (DCSP) Perchloric acid digest AAS finish (101)
Zn	ppm	2	Dry,crush,split,pulverise (DCSP) Perchloric acid digest AAS finish (101)
Ag	ppm	1	Dry,crush,split,pulverise (DCSP) Perchloric acid digest AAS finish (101)

Geochem. results :

Au	Au(r)	Cu	Pb	Zn	Ag	As	Mo
(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
0.010	0.015	75	<5	10	<1		

Bi	Hg	F
(ppm)	(ppm)	(ppm)

Notes :

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Specialists in Mineral Exploration:
Geology and Computing

Figure 2. Example of relational links between data and relevant libraries as shown by decoded rock chip ledger Terra Search EXPLORER II Data Base Management

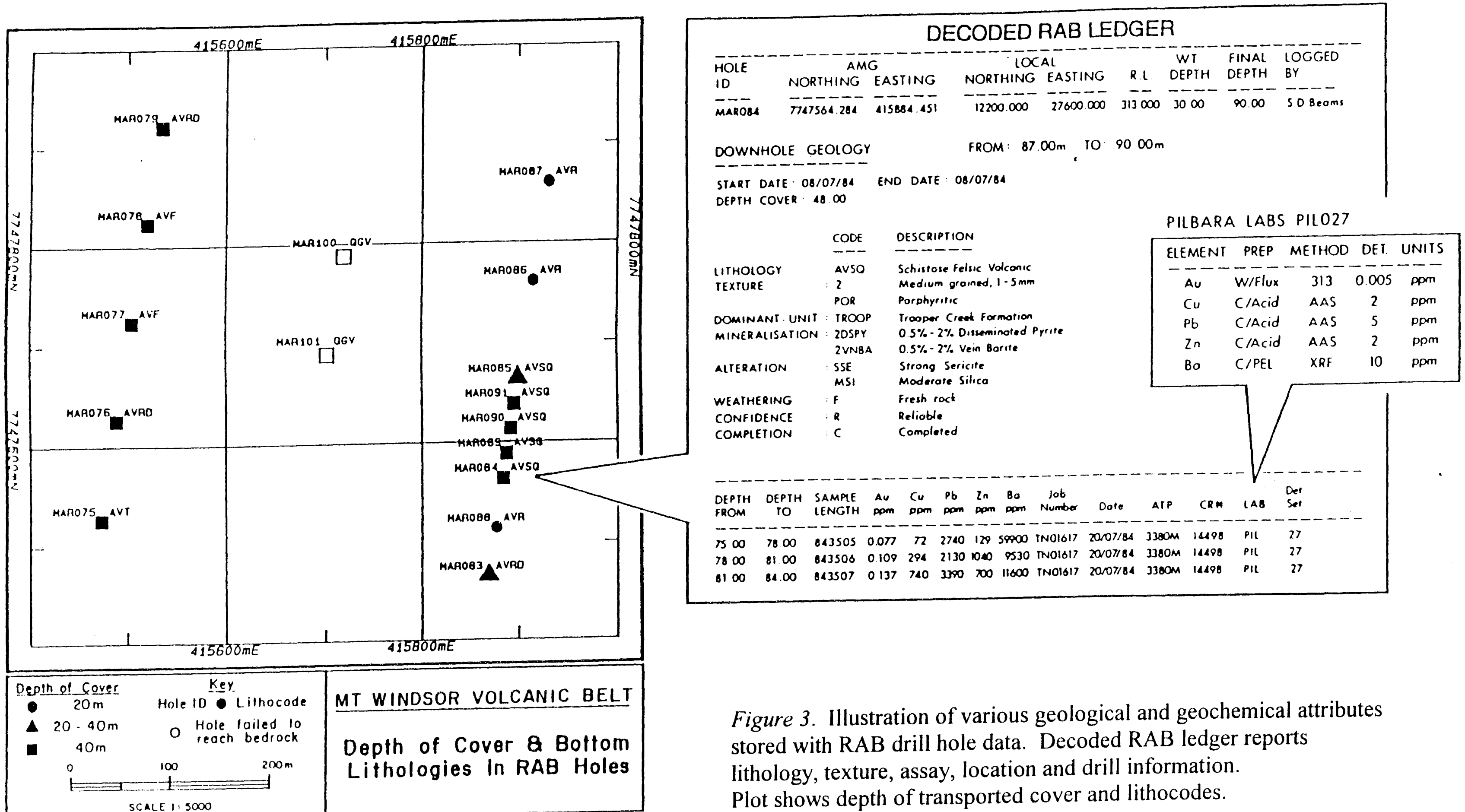


Figure 3. Illustration of various geological and geochemical attributes stored with RAB drill hole data. Decoded RAB ledger reports lithology, texture, assay, location and drill information.
Plot shows depth of transported cover and lithocodes.

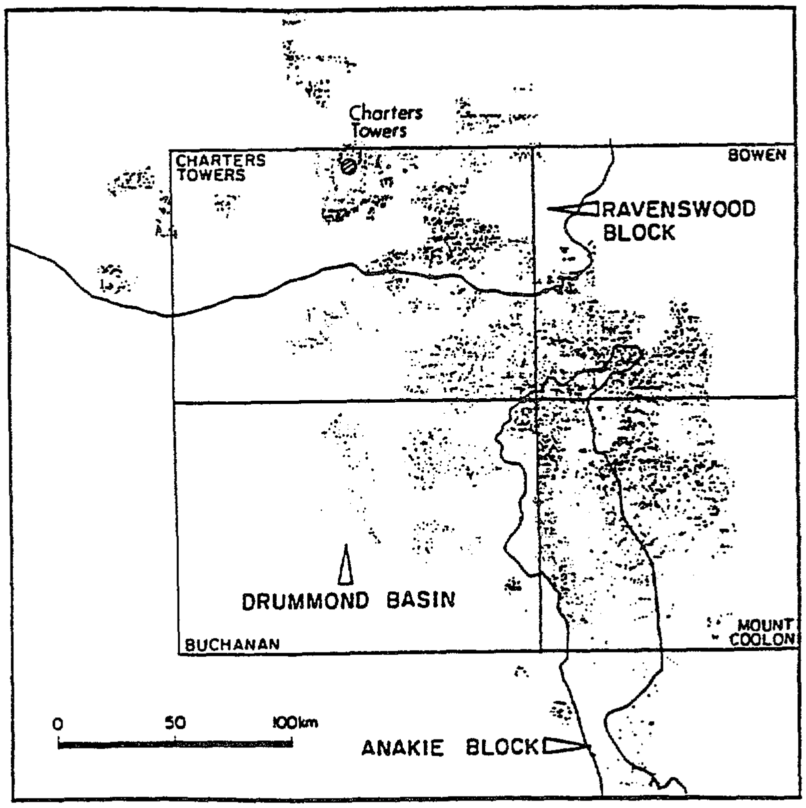
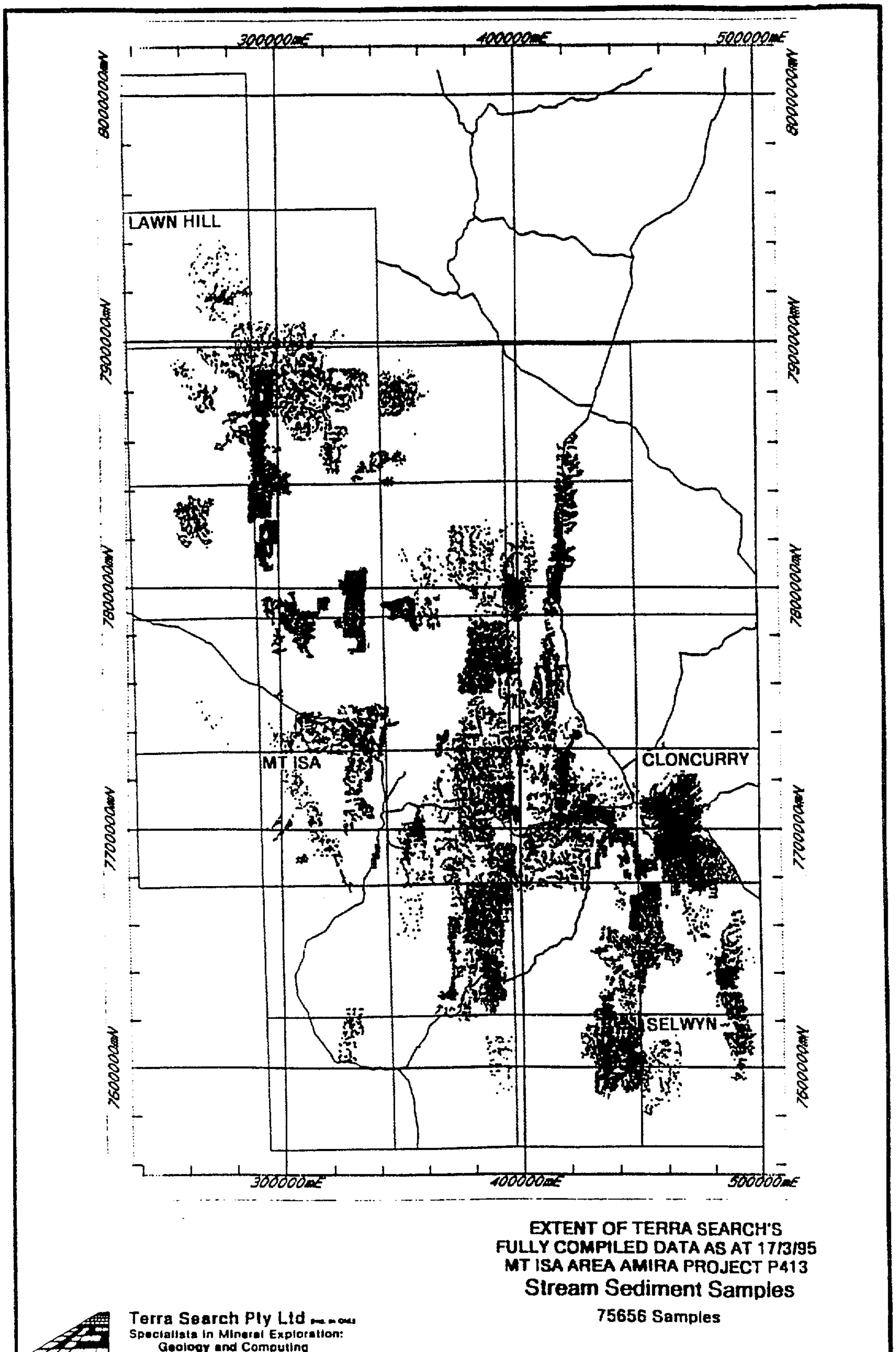


Figure 4. Distribution of BCL Stream Sediment sample data Drummond Basin and Ravenswood Block. 1:250 000 sheet boundaries shown. 14 000 points plotted.


300000mE
400000mE
500000mE
8000000mN
7900000mN
7800000mN
7700000mN
7600000mN
LAWN HILL
MT ISA
CLONCURRY
SELWYN
EXTENT OF TERRA SEARCH'S
FULLY COMPILED DATA AS AT 17/3/95
MT ISA AREA AMIRA PROJECT P413
Stream Sediment Samples
75656 Samples
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Geology and Computing

Figure 5

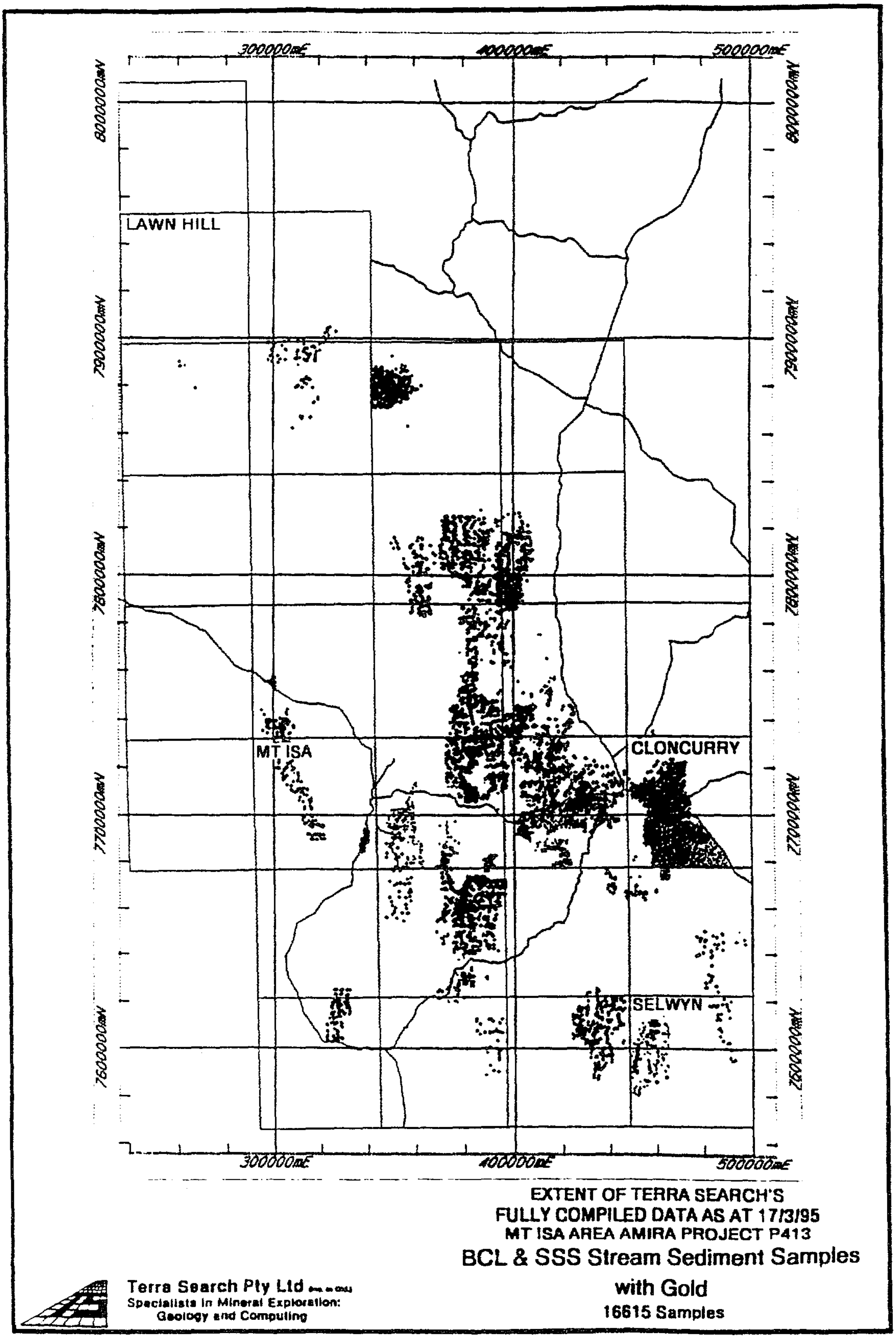
300000mE
400000mE
500000mE
8000000mN
7900000mN
7800000mN
7700000mN
7600000mN
LAWN HILL
MT ISA
CLONCURRY
SELWYN
EXTENT OF TERRA SEARCH'S
FULLY COMPILED DATA AS AT 17/3/95
MT ISA AREA AMIRA PROJECT P413
BCL & SSS Stream Sediment Samples
with Gold
16615 Samples
Terra Search Pty Ltd
Specialists in Mineral Exploration:
Geology and Computing

Figure 6

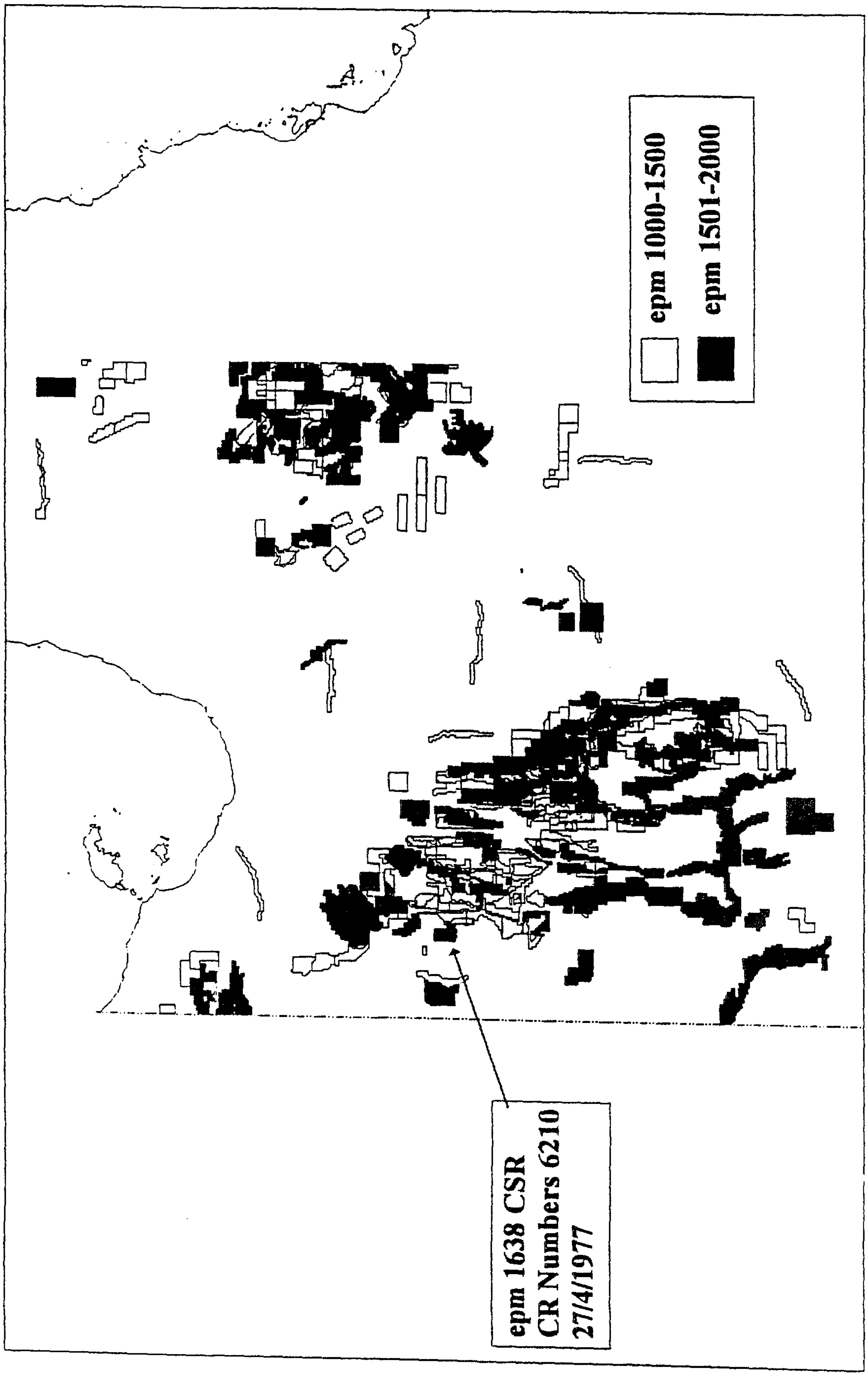

Figure 7. EPMs 1000 to 2000 for north west Queensland subsetted on EPM Number.

GIS in WMC Exploration Division

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Phone: 09 479 8465, Fax: 09 479 8444, e-mail: lyle.burgess@wmc.telememo.au

WMC recognises that the general lack of a coherent approach to the organisation and management of spatial digital data has led to poor decision making processes, the compilation and incorrect use of data, lost time, high costs and thus lost opportunities in mineral exploration. WMC staff routinely use systems to process data with an element of geographical location, to assist their business decision-making. Many of WMC's business activities involve processing such geographic or spatial data.

The cost of collecting this geographic information is many millions of dollars each year. It is strategically important. Its organisation and management is very important.

A proposed WMC vision to handle geographic information and data is to routinely use systems to process and interpret data associated with geographical locations, to assist in their business decision-making and to freely share such data amongst those who need it, independently of geographic location, discipline, or software package. It is clear that the management of geographic information is far more than just providing a few specific products. It requires an overall approach.

WMC has many software products which use geographic information, and it is likely that the range will increase.

eg:

Image Processing - ER Mapper
Technical Database - INGRES
Digital mapping and CAD - Microstation + polygon processing routines.
GIS - Arc/Info

Other Products include:

Micromine, Datamine, Surpac, internal software packages, etc.

A plan for the data architecture is to have a master copy of some datasets held in the WMC Corporate Data Centre facilities on the corporate VAX. Regional office data will be stored on a local file or database server such as Ingres or Oracle to minimise WAN traffic. Specific products will load data into their own proprietary formats for efficient processing.

Principles underpinning this approach include:

Data Collection and management
Quality - content, accuracy, currency
Lineage

Management

Effort and expense in Procedures
Data acquisition and entry
System implementation (training and support)

(Hardware and software costs are relatively minor)
Procedures and Standards are critical.
Must be business oriented
Sufficient resources must be allocated - support, maintenance, training

Technology
Industry accepted packages
Ease of use for sporadic users
Integration with other products

Support
Standards development
User training / education
Ongoing advice
Seamless integration of software packages

Implementation
Spatial data to be captured clean for ultimate use in GIS
Guideline polices and procedures put in place
Core units of expertise to be developed
Recommendation of GIS and other products

In terms of the implementation of a GIS Strategy exclusively within WMC Exploration Division we envisage a three tiered model with

1) Arc/Info at the top level. It would be used for cartographic quality map production, high level modelling and targeting - fuzzy logic, WOE, AI - This would be maintained by a small core group of centralised specialisation.

2) ArcView at the middle level. This desktop GIS Mapping Package would be used in Regional offices by Exploration Geoscientists.

3) Microstation at the third level. It would be used for digital mapping and data capture, cleaning and CAD. Data would be cleaned by using the microstation-based WAWA polygon processing routines so that data could be imported into Arc/Info and ArcView directly either as Arc/Coverages or as shape files.

Each regional office would have and a database server. This is currently INGRES but may be ORACLE in the future.

The above software packages fit nicely into WMC's current setup of having ER Mapper on a Sun workstation in every regional exploration office.

ISSUES TO BE RESOLVED

Resolving short term interfacing of software packages.
Implementation of the database server to hold ALL data (with topology).
Allocation of responsibility for data acquisition, coordination.
Procedures and facilities for indexing geographic information.
Spatial and graphical access to other corporate information.

Integration of GIS and Hydrologic Models

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Lecturer, Professional Officer, and Senior Lecturer respectively
School of Civil Engineering, The University of NSW

Abstract Geographic Information Systems (GIS) provide many capabilities for hydrologic modelling that were traditionally performed by hand. The ability to directly integrate GIS technology with hydrologic models promises a significant increase in modelling consistency, accuracy of data extraction and preprocessing, and ability of data exchange between different models. Although the promise is there, actual integration process requires great care and is full of traps. Application of GIS for floodplain delineation is used to demonstrate the benefits and pitfalls of GIS-model integration. A case is made for development of a generic hydrologic data exchange format that would enable easier model to model and model to GIS data transfer.

Introduction

Hydrologic processes are intrinsically spatial as well as temporal in nature. Mathematical models that try to describe components of the hydrologic cycle use spatial information at different levels of detail. The simplest hydrologic models might lump all the spatial variability of a process into a single computational element. On the other side of the spectrum are spatially distributed, physically-based hydrologic models that require input of numerous parameters at many locations in and around the area of interest. In both cases, model parameter(s) could require spatial averaging or point sampling of relevant properties over the watershed area.

Geographic information systems (GIS) with their capability to manage and manipulate spatial data provide a variety of useful tools that can be used in preparation of input data for hydrologic models. There are several examples where GIS has been used not only to store and prepare the data for the model, but also as an interface development platform, where the intricacies of data preparation and formatting are shielded from the user by an interface fully developed in GIS (NCGIA, 1993; AWRA, 1993; IAHS, 1993).

There are three main features of GIS that are useful in hydrologic modelling; these are spatial data management and processing, visualization, and interface development. Usefulness of these features will be shown through examples of GIS integration with hydrologic and hydraulic models used for floodplain delineation.

GIS Database for Modelling Support

The most obvious use of GIS to support hydrologic models is basic spatial data handling. A GIS database can be developed to store spatial data required for hydrologic analysis. Typically this database would include in individual coverages the watershed areas, land use, land cover, stream network, terrain representation, soil type, etc. Each of these coverages could have some properties attached to it that are relevant for modelling. For example, the soil type coverage could contain data about the infiltration characteristics of the soil, or the stream network coverage could contain information about section length, slope, and roughness.

Database development could be manual or partially automated. Subwatersheds and the drainage network could be automatically delineated from the terrain model. The surface slope could also be determined automatically from the terrain model, while its roughness could be determined by overlaying it with a land use/land cover coverage. In fact, most of the information that is topographically based could be automatically extracted once the terrain model is available.

Unfortunately, these kinds of operations are often being called hydrologic modelling and are used as an example of how GIS can do hydrologic modelling. *This is not the case since there are no aspects of hydrologic cycle that are being represented in this kind of analysis.* These operations might support hydrologic modelling, but they do **not** represent hydrologic modelling. It would be more appropriate to call these operations topographic modelling.

Use of GIS for hydrologic data and model parameter development offers an opportunity to systematise methods for their derivation and extraction, and improve quality control in model implementation.

Visualization and Result Interpretation

Visualization in hydrologic modelling does not play a significant role compared to some other areas of engineering modelling. It is however a useful tool, specially in data preparation and result analysis where proper presentation of data can speed up the modelling process, reduce mistakes, and help interpretation of results (more on that in the section on interface development).

Such tools are also available from specialised modelling support software. Often, they are better that the standard display and mapping tools that GIS offers, since they are specially tailored for model's particular needs. GIS' strong point is its capability to integrate data coming from various sources at the same geographic reference level and in some specialised tools that are not available in standard hydrologic support tools.

A good example is floodplain analysis. GIS can be used to develop input for models used to delineate the floodplain. While GIS methods might be inferior to some specialised tools that perform the same tasks, the power of GIS lies in the use of data defining the floodplain, once it is computed. For example, by combining the floodplain extent with geocoded street network and using GIS network tools, it would be possible to determine the addresses of property that are flooded, best routes for evacuation to emergency shelters, disabled roads, etc. These capabilities do not exist in a hydrologic modelling support program. Whether this is a reason to use GIS only is questionable, and is discussed later.

Interface Development

In a complex modelling systems where several, often diverse, tasks are performed by different programs (models), interfaces provide linkage between the components and define the overall systems' usability. Interfaces can be grouped as:

a) data interfaces, that define how data between different models or database management systems are shared and/or exchanged.
b) user interfaces, that define interaction between the program(s) and the user.
c) command interfaces, that define how different components of the modelling system interact with each other and control each others execution.

Full-featured GIS provide tools for development of all three types of interface. That makes them feasible for usage as the main environment for complex modelling systems, that is, they can be used as the 'glue' to combine all the components into an integrated working environment. Decisions on the system architecture are complex, and the proper design is imperative for successful model implementation. GIS should not be automatically considered as the tool of choice for system integration, but rather as one of the possible solutions.

A complex modelling system can include several specialised products. For example, the floodplain modelling system could consist of a GIS for storage and manipulation of spatial data, a relational database management system for manipulation of non-spatial data, specialised database system for handling of temporal data, some standard statistical packages for frequency analysis, and a variety of specialised hydrologic and hydraulic models. Such a system could lead the user through the development of the database, selection of models to be used, model input preparation, running of the models, and finally, result interpretation.

Integration Methods

There are several methods of integrating a specific modelling method or model within GIS. They can be classified as:

a) Linked, where independent programs share data through data exchange programs, and lack common user interface or command control ability. This is the simplest way of interfacing requiring little effort in development, but significant effort in maintenance and operation of the system.
b) Integrated, where independent programs share data through data exchange programs hidden from the user, and have common user interface and full execution control. This is a more complex integration method. It requires moderate to significant development effort, moderate maintenance, and little effort in operation.
c) Embedded, where full modelling capabilities are implemented within GIS (or GIS capabilities implemented within modelling environment), and there is a unified GIS/model database. This is the most complex integration method. It requires significant development effort, moderate maintenance, and little effort in operation.

The main difference between integrated and embedded integration method is the location of the model and its database. In the integrated method, the model and its database are external to the GIS, while for the embedded method, the model with its database is programmed within GIS (it becomes an integral part of the GIS tool set). From a user's prospective, this can be completely transparent, but it makes a significant difference for the system developer.

Again, which method of integration is to be used will depend on the specific tasks that the modelling system is trying to accomplish. In general, when modelling techniques involve complex numerical solutions (e.g. time-variant, multi-dimensional, multi-phase phenomena described by partial differential equations) it is better to maintain the model separate from GIS. Numerical models tend to be written and maintained by different people from those operating GIS and such an arrangement facilitates development and maintenance of both components. In addition, this arrangement does not place any extra overhead on the numerical solution that implementation within GIS might impose.

Need for Generic Data Interface

In a complex modelling system, it is often necessary to share data between several models or programs. Each of these programs can be looked upon as a data provider or a data user. Often, a single program is both a data provider and a data user. For example, an open channel flow model is a data user when requesting input data from GIS, but is a data provider when giving information back to GIS about water levels at each cross-section. If integration of these programs is to be achieved in a conventional way, a two way data interface needs to be developed for each pair of applications. For N data providers and M data users there are NxM interface programs. Rationalisation of the interface can be achieved by developing a generic data exchange format that all of the data providers and users would be able to read from and write to. In this case, only N+M interface models would be needed, significantly reducing programming effort. Development of such a data exchange format is currently in progress (Djokic et al., 1995).

Floodplain Modelling

Often rainfall-runoff and open channel flow models are used for floodplain delineation in areas where long term flow measurements are unavailable. In these cases, or more generally, when reliable flood frequency information is not available, the floodplain delineation procedure involves the following steps:

a) development of design rainfall of selected frequency over the area. This is accomplished either by statistical analysis of existing rainfall data over the catchment, or by using standardised 'cookbook' methods developed from regional analyses of historical events, often developed and published on a national level (e.g. I.E.Aust., 1987, for Australia).

b) conversion of design rainfall into runoff at selected locations. This task is performed by using one of the many hydrologic rainfall-runoff models. These models will often require spatially distributed information, either in its raw form or in a preprocessed form, as model input parameters.

c) conversion of runoff computed in step (b) into water surface levels along streams. This is done by using one of many hydraulic models for analysis of open channel flow situations. These models have different levels of complexity based on their spatial character (one, two, or three dimensional) and Temporal character (steady-state or time-variant).

d) once the water surface levels are found in step (c), they can be superimposed on the topographic maps to identify the floodplain, depth of water at different locations, and other information needed for flood hazard assessment.

More detail on this general procedure or any of the particular methods can be found in most hydrologic textbooks, e.g.. Chow, et al., 1988.

GIS Implementation of Floodplain Modelling

Each of the four tasks identified in previous section has spatial characteristics and the implementation of these tasks within a GIS will be describe now. The presented implementation is only one way of utilising GIS; there are several other possibilities which may be more or less complicated than those presented, and which will accomplish similar results. Such solutions depend on the available data, applied modelling methodology, and integration effort.

Rainfall analysis

Development of design rainfall for a given location based on standardised methods is a common and straight-forward task. It usually involves interpolation of rainfall depth or intensity for selected duration and return period from published maps of isopleths (lines of equal rainfall intensity). It could require reading of several numbers from a series of maps, and some computations, but is, in principle, easily implemented within GIS. Isopleths are used to form a surfaces from which a value can be directly read for any selected location, return period, and storm duration. If necessary, an external program can be used to use those numbers to compute the final rainfall. GIS can also be used to distribute the rainfall spatially, if such a procedure is defined and desirable.

Rainfall-runoff analysis

This is probably the most complex hydrologic method(s) to be implemented in GIS. The complexity stems from a large number of techniques that have developed over many years, which are used to perform rainfall-runoff analyses. A lot of these techniques are empirical and site specific, making them generally unusable. Implementation in GIS is not a question of lack of GIS' ability to handle the necessary data and parameter extraction method, but rather a question of systematic and appropriate application of these methods.

A typical example is use of a *watershed slope* as an input for computations of parameters used for unit hydrograph analysis. The problem is that there are several methods that can be used for computation of the required parameter, and each method uses a differently defined watershed slope. To make matters worse, these methods can be derived for a narrow set of conditions and should not be transposed to other regions without testing them first. There are a number of other examples of this type.

Djokic (1994) discusses the development of an expert system application to GIS data to support decisions regarding hydrologic modelling. Such systems offer potential for advising the user on the applicable methods based on the type of the data available or through a critical review of the proposed modelling methodology. Knowledge-based programming techniques provide a bridge between data and models and can provide the first step in quality control.

Open channel flow data preparation

Open channel flow computations can be quite computer intensive, specially when dealing with multi-dimensional and time-variant problems. Over the years, a number of computer programs have been developed to perform those computations. These programs have been optimised for that specific job and direct implementation within GIS is not feasible due to the complexity of the computations, or sometimes undesirable due to legal constraints. This kind of analysis, therefore, is a good candidate for GIS linkage or integration, but not embedding. GIS would be used for data preparation, while the external model would take that data and perform the actual computations outside of the GIS engine (and overhead).

Once discharges or inflow hydrographs are computed for selected locations through rainfall -runoff analysis, the preparation of input data for open channel flow computation consists of identifying locations of cross-sections and defining their properties. Some of these properties, including cross-sectional profile, roughness, distance from the next cross-section, etc., can be defined through GIS operations. Some other parameters, such as expansion or contraction coefficients are not easily definable in GIS and should be left for input by the user (of course, that information can then become a part of the GIS database). GIS can also be used to develop a user interface for parameter extraction, and even further, to completely replace the interaction with the modelling program (Djokic et al., 1994).

Floodplain delineation

Once the water levels have been computed by the open channel flow model, these levels are transferred to topographic maps to establish the extent of flooding. This operation can be performed by GIS that has surface modelling capabilities. Terrain surface (which is used for cross-section extraction) is intersected by the water surface that is generated based on level information coming from the flow model, and the intersection of those two surfaces defines the water extent. GIS can perform this operation faster and certainly more accurately than it can be done manually.

A series of such floodplains can be determined for different time steps (for time-variant problems) and animated, showing temporal distribution of flooding. Such activity would be extremely time consuming if performed manually.

Conclusions

GIS has many capabilities that can be used in hydrologic modelling. The level of use, however, will depend on the complexity of the task at hand. Certain operations could be completely embedded into GIS, while for more complex numerical computations, the computational aspect (numerical engine) could be kept separate, with GIS providing pre- and post-processing. With the proper use of standardised data exchange formats, the linkage of GIS and hydrologic/hydraulic models can be rationalised, and made more efficient.

Diversity of hydrologic techniques and sometimes confusion about their use, can pose special problems for effective GIS implementation. Care has to be taken to ensure that proper data extraction techniques are applied for the selected hydrologic methods and geographical locations. Rule-based systems can help making this transition to automated data preparation more efficient and consistent.

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ISSUES FROM APPLICATION OF THE AUSEABED MARINE GIS / DATABASE IN OFFSHORE SCIENCE AND ENGINEERING: INTERFACING WITH MODELLING PROGRAMS, ERROR BUDGETS

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Overview of the database

The Ocean Sciences Institute has designed, developed and populated a GIS database of the seabed for the Australian maritime area - AUSEABED (Jenkins & Rawson, 1995; see Fig. 1 herein). The structure includes information on seafloor topography, sediment types, engineering and acoustic physical properties, natural and contaminant geochemistry, near-bottom currents, acoustic and visual imagery, and rock/reef/sandwave areas. Partners in the development are the RAN Australian Oceanographic Data Centre (AODC) and the Australian Geological Survey Organisation (AGSO).

Three primary technical goals for the project have now been met through deliberate design of the data structure:

(i) to deal in an open and adaptable way with seabed point/trackline/area data from diverse data sources;
(ii) to build specialised tools/applications for handling marine data;
(iii) to be readily exportable to a variety of GIS and relational databases for specialist applications in research and industry.

A focus on original 'point' rather than polygonized data gives the database the highest degree of adaptability in modelling applications and assimilation of new data.

The raw AUSEABED dataset can be enhanced and extended through a set of modelling processes to bridge data gaps or to produce thematic maps and statistics as aids to engineering feasibility studies, offshore management policy and programs of general research. OSI uses a range of relational database programs and GIS to address and display AUSEABED.

In performing a range of science and engineering applications for marine seabed data in the GIS environment, OSI is encountering issues which must also be of concern to other users of geological databases and GIS - onshore and offshore. Those of immediate concern to us are:

(i) interfacing large computational packages with GIS;
(ii) the lack of error handling facilities and depictions of error in GIS.

Interfacing intensive real time modelling and GIS

The detection performance of naval sonar systems is dependent in a complicated way on seafloor sediment type, water depth, seafloor roughness and oceanographic conditions. Using the AUSEABED database and its enhancements, the sonar performance for a navy ship can now be modelled for any location around Northern Australia. In this field it is extremely important that the performance prediction can be updated in real time as a naval unit moves about in operations and as oceanographic conditions change with weather.

The core sonar performance modelling requires that large computational acoustic prediction packages like SNAP and STOKES draw on the contents of the database through a GIS spatial enquiry and send the results of the resulting calculations to a GIS for plotting and query. However, running the sophisticated acoustic propagation modelling packages in real time in the naval operational environment is not practical for these reasons:

(i) they may take periods from minutes to hours to run - a luxury not available in naval operations;
(ii) the numerical methods are occasionally unreliable and fail to converge to a solution;
(iii) an understanding of their running and application is not given to the personnel at sea;
(iv) the system needs to be tamper proof;
(v) portable variations may be needed in small boats and helicopters.

An obvious solution to these problems is to pre-assemble a set of tables containing the results of runs of the packages under a range of conditions expected within the naval operations area. These matrices need not just be the final propagation values, but could hold the coefficients of simplified ('fitted') functions that reflect the variation in propagation values as changes in seabed type, roughness and water properties take place. Reporting the coefficients to simplified functions would also reduce matrix size and look up time.

OSI has made an initial implementation of this process using:

(i) AUSEABED seafloor data from the offshore WA-NT zone;
(ii) data recalculation for pertinent acoustic variables like the ratio of bottom water and topmost sediment sound velocities;
(iii) GIS functions in SPANS® to query the seabed properties around the naval vessel to a radius of 100 km;
(iv) a look-up-matrix of acoustic propagation values calculated through SNAP (Jensen & Kuperman, 1983);
(v) customised programs to communicate the data between these packages; and,
(vi) GIS display tools in SPANS®

An example is displayed in Figure 2 (without the actual propagation values).

The choice between running real-time packages in interfacing with GIS and using pre-assembled look-up-tables could be applicable to many situations in science and engineering - including offshore environment slope stability and sediment transport.

Error handling

The last point is a particularly serious shortcoming because right now the planning for large projects is being made on the basis of GIS manipulations of complicated datasets containing measurements - each with a range of error.

There has been some interest in error as it affects GIS (*eg* Kiiveri, 1995) but the problems of:
(i) how to calculate (propagate) error bounds through GIS operations, and
(ii) how to display error/uncertainties on GIS generated maps
have not permeated through the community of GIS users or software companies sufficiently. Risks of a financial and environmental nature are therefore not being properly assessed.

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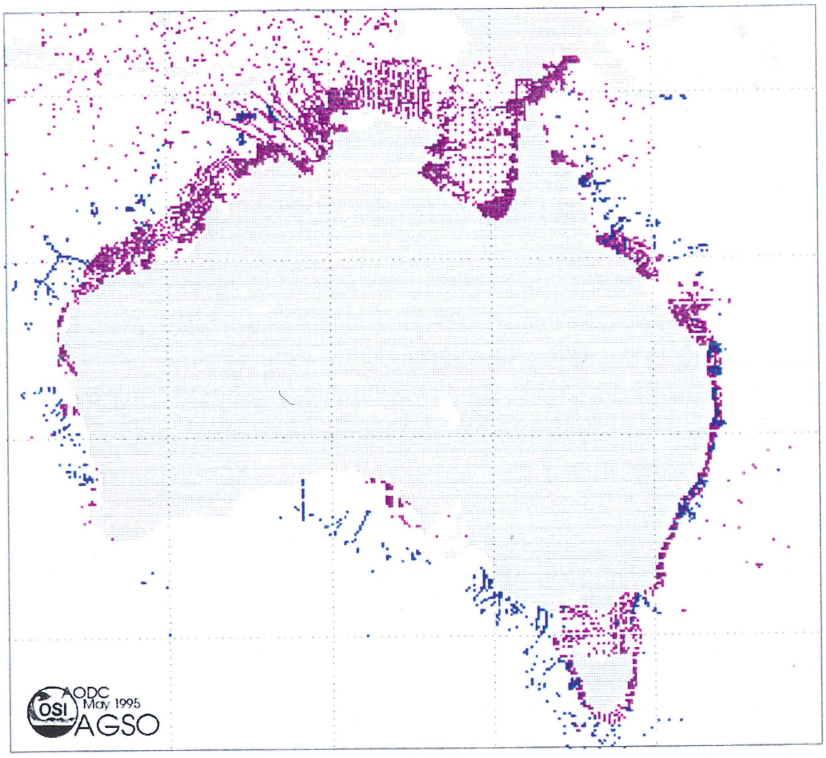

Fig. 1. AUSEABED Sample coverage

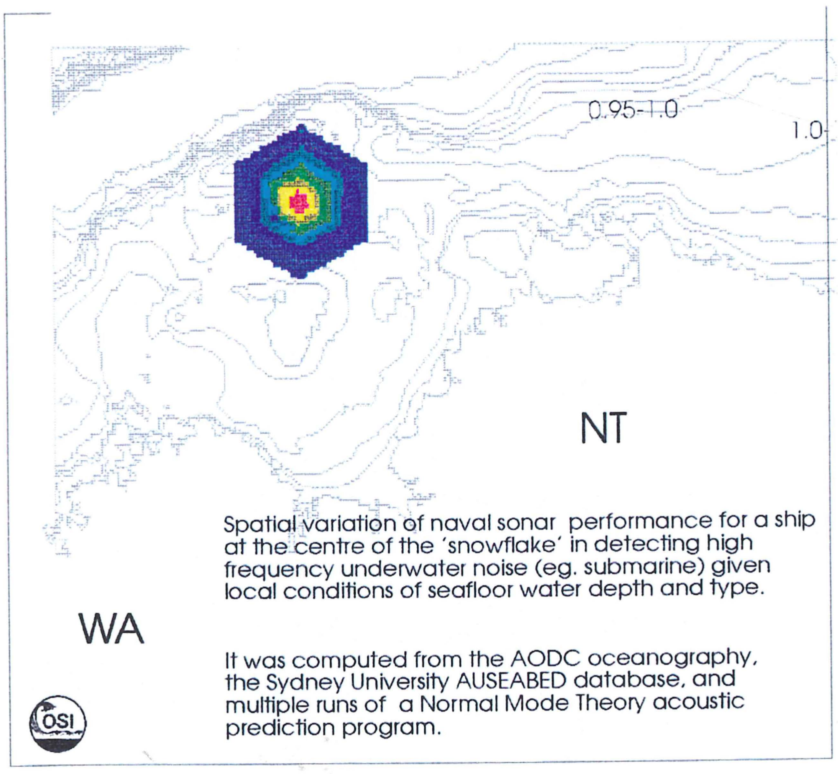

Fig. 2. 'Loss by range' - based on NMT Optimum Range

Integration of GIS and Modelling in the AGCRC

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Abstract: The Australian Geodynamics Cooperative Research Centre (AGCRC) is engaged in a substantial new synthesis of the geodynamic history of Australia. This includes both compilation of existing models, and new interpretations of critical areas. Central to the project is the use of computer based modelling and visualisation techniques. The aim is to capture and present the outcomes of this work in an interactive digital environment, and make this available to the exploration community.

GIS will play an important role. Yet many important functions for geodynamic modelling are not available within GIS managers, particularly 3D capabilities. These may be covered, however, by existing commercial and non-commercial software, by tools under development within the AGCRC and collaborating and related organisations, and by as-yet unannounced future packages and specifications.

Stitching these together in an effective way is a significant challenge. There are a number of important considerations. For example, it will be necessary to service users with different levels of competence: while advanced users will want to take advantage of the native interfaces of the various applications, casual users will need an intuitive interface with only summary functionality. Integration with related information services, such as @ngis, will be a basic requirement. It is critical that metadata (describing details of the underlying observations and the modelling and interpretation methods used to derive higher level entities, by whom) be available to allow a user to determine their confidence in a particular feature or component. Controlled access to commercially sensitive datasets will need to be managed. And since geology is a historical science, the incorporation of time into GIS representations needs to be carefully thought out.

Some important data organisation issues impinge on the system acting as an integrated package. Data-model transformations, as well as simpler reformatting, need to be accommodated in order to share information between the components. Although SDTS provides a basis for 2D representations, this is far from complete for the geological applications here. Work is underway in several forums aimed at producing a superset of the various data-models in use together with tools for conversion between these.

Finally, although adherence to standards at some level will be essential in achieving such a system, it is important that these do not act as a straight jacket, but are flexible enough to ensure that the best technological and algorithmic developments can be taken advantage of easily. The use of standard specifications such as http/cgi and CORBA should facilitate this and avoid automatic obsolescence. A prototype interface based on the WorldWideWeb has been developed.

KEYWORDS: geodynamics, geology, modelling, 3D, 4D, spatial information systems, data transfer, interoperability, networking

INTRODUCTION: The AGCRC

The Australian Geodynamics Cooperative Research Centre (AGCRC) has assigned itself the mission

> *To develop the geodynamic framework, in partnership with the Australian minerals and energy industry, which enhances its capacity to discover world class deposits.*

This is an ambitious undertaking, motivated by the premise that the location of large ore bodies is controlled by geological structure and tectonic setting. A better understanding of geodynamics will therefore aid the discovery of economic mineralisation.

A variety of activities are being carried out to serve this end, including new data collection, re-analysis of critical areas, and compilation and synthesis of geological and geophysical information on regional and broader scales. The particular focus is on the geodynamics and structure of the lithosphere and its influence on mineralised terrains. The outcomes will thus address the 3D (geometry) and 4D (history and geometry) of Australia at a range of scales.

An initial list of continent-wide datasets has been identified (Table 1) to assist in establishing the framework. These are either available now, are under compilation, or will be the outcomes of AGCRC projects. Note that, although many of these datasets are "maps" which can be managed in a conventional GIS, we have also identified at least two broad-scale 3D datasets (the velocity structure of the lithosphere and mantle, respectively.)

In addition, regional AGCRC projects are currently taking place in the NW Shelf, Mt Isa, Eastern sedimentary basins and New England fold belt, Menzies-Norseman belt in the Goldfields, Lachlan fold-belt, Broken Hill and the Hamersley Basin. In most cases these projects will produce 3D models of all or parts of the areas of interest, generally supported by an interpretation of the processes and history that produced the current geology.

The collection of models and interpretations resulting from AGCRC projects, including information at all the scales (with regionally varying resolution) will compose a synthesis of Australian Geodynamics which has been called the "4D Geodynamic Model" or 4DGM.

Technology

As far as possible, the intention is to deliver the results of AGCRC projects in digital form. This will not be simply in the form of digital datasets; that is an agency function appropriately fulfilled by AGSO, the state surveys, and other specialised organisations. The AGCRC is mainly concerned with interpretations and models derived from the observations. Although those could also be made available in the form of "datasets", such as grids or "coverages", in most cases they will be most useful when presented on-line in the context of software modelling packages within which they can be examined. Visualisations of the models should thus be controlled interactively by the consumer: in 2D (eg maps, sections, graphs), 3D (eg solid models viewed in pseudo-perspective), and 4D (eg dynamic models, animations, movies) with control over which themes and properties are visible in the selected area of interest, and from what scale and point-of-view.

The role and limitations of GIS

Conventional GIS systems have a clear role to play in servicing some of these objectives. In particular, the current technology provides good tools for:

- organising map databases
- linking geographic objects to relational database tables
- basic 2D modelling, such as topographic and morphologic operators, map algebra, etc
- high quality cartographic output.

Furthermore, there is a substantial existing base of customised capabilities, macros, etc for several of the popular software packages which provide specialised geological capabilities. Incorporating at least one of the popular GIS platforms would also enhance the compatibility for data transfer between AGCRC projects and external organisations.

Table 1. List of continent-wide datasets

Data	Resolution	Source
Elevation model - onshore	5'	NOAA Terrain Base
Offshore Bathymetry model	5'	NOAA Etopo5
SeaSat offshore gravity data	5'	NOAA
GeoSat offshore gravity data	5', south of 30°S	NOAA
Elevation model - onshore	9"	AGSO + AUSLIG
Magnetic Anomaly map of Australia	interpolated to 15"	AGSO
Gravity map of Australia		AGSO
Earthquake catalogue		NOAA
Compilation of stress measurements		NOAA
3D Mantle velocity map		Harvard tomography project
3D Basement velocity map		ANU Skippy project
Moho Depth	interpolated to 15'	from Collins [1991]
Depth to Basement		AGCRC
Metamorphic map of Australia - (peak P-T conditions)		AGCRC
Australia-wide Fission Track ages		AGCRC
Heatflow	interpolated to 1°	from Cull [1991]
Lineament traces		AGCRC
Tectonostratigraphic events		AGSO+

However, it is also very clear that delivery of the 4DGM demands capabilities substantially beyond existing GIS technology. Important capabilities which are either missing or not optimised include:

- o 3D - data indexing, solid modelling and cross-sections, structural geology, volume calculation and reserve estimation
- o time and 4D - including geodynamic reconstructions, mechanical modelling, and time + space indexing
- o image processing, potential field modelling, etc which, if present at all, have poor interactive performance.

The higher dimension features are clearly a dominant concern. Although some 3D functionality can be emulated using layers in a GIS, this is only generally realistic for simple, basin style geology. Full 3D solid modelling is required for high angle structures, and is essential for checking of consistency.

An important constraint on any model of 3D geology, however, is that it must be possible to build it with a plausible sequence of geological events. This requires an historical or 4D approach to solid modelling, in which time is a control parameter of processes, and not simply the index of a sequence of snapshots. The historical approach is the basis for the geological part of the Noddy simulation software.
Indexing of the additional dimensions in the conventional sense, extended to 4D, is still important. Stratigraphic principles need to be used for the age of objects, allowing correlations of events to be used as a powerful tool in tectonic modelling.

Finally, linking the geometrical database to physical modelling tools, such as geophysical potential field and mechanical simulations, is needed to allow interactive evaluation of geodynamic interpretations.

Other software tools

Many of the required capabilities are provided by other software, including industry standards, new products and combinations of these. Projects within the AGCRC are currently using, for

GIS & Image processing:	ArcInfo+ArcView, GRASS, MapInfo, ER Mapper
Database managers:	Oracle, Filemaker Pro
Geometry modelling:	Microstation, Canvas, Caddsman
Specialist geology modelling:	Petroseis, Vulcan, Noddy
Mechanical modelling:	FLAC, UDEC, FiDAP, Basil
Visualisation:	Iris Explorer, AVS, Macromedia Director, Wavefront.

These are being used in an *ad-hoc* way to assist in particular aspects of projects, sometimes in rather complex combinations. For example, as part of an AGCRC project to model the Bowen Basin, seismic interpretations are captured in Petroseis, and some modelling of stratigraphic surfaces is completed there. Modelling the faulting, however, requires interactive 3D visualisation, for which we use Maptek's Vulcan to select inputs for external, custom surface-generating software. Vulcan, however, cannot cope with the amount of data in the complete Petroseis grids, so these are decimated in an intermediate step within GRASS using a scheme whereby high resolution is retained around the faults, but much lower resolution elsewhere, and then imported as triangulated surfaces in Vulcan. The results of the 3D modelling are exported to AVS for visualisation, and will also be the input to some mechanical modelling.

A major challenge is that, in contrast to the effort that has gone into GIS where both official and *de-facto* exchange standards have emerged and are progressively being adopted, these are still lacking for 3D except in the most basic way (eg DXF is widely supported for points, curves and polylines, but has no topology and minimal attribution.) There are some possibilities: for example SGI have attempted to position their Inventor technology to fulfil some of this role, by putting Open Inventor in the Public Domain. And in 4D, a VRML (Virtual Reality Mark-up Language) is being proposed.

As an interim measure, we are proposing to use AVS within the AGCRC as a standard for transfer and visualisation of 2D and 3D objects and for the production of some animations. AVS is a modular, multi platform prototyping visualisation system. Add-on products allow data exchange and data sharing with other widely used systems such as ArcInfo, and there is considerable informal support from a large user community, through newsgroups and web-sites, including access to many newly developed specialised modules.

Requirements for an integrated system

Our intention is to use any or all of these tools, together. Effective use of this variety of modelling tools imposes requirements in the following related areas:

- Data exchange and data sharing
- Multi-site access to tools and data
- User interface

Interoperability between such a heterogeneous group of "legacy" applications (ie existing, already functional programs, with their own interfaces, and underlying data models) is a complex task. Although there may be opportunities for dynamic linking, or even embedding some smaller applications within more comprehensive systems, data exchange between programs will be the main mode of interoperability in the immediate future.

Format conversions, data exchange

Anyone who has used any of the applications listed above has had to confront the issue of capturing data into the program. In many cases the information is already in the computer in a format for another piece of software, so the task is to exchange data between these software packages. This will be the main challenge for the integrated system envisioned within the AGCRC.

Most software has specific import/export modules for data from other packages built in, in some cases utilising an intermediate format, such as DXF for line data. However, frequently special filters have to be constructed. For the Bowen Basin project discussed above, conversions between Petroseis, GRASS and Vulcan are routinely carried out, and a number of methods for doing this have been developed, depending on which aspects of the data are required (Figure 1). It should be noted that data exchange is generally much more than a matter of converting record and file formats.

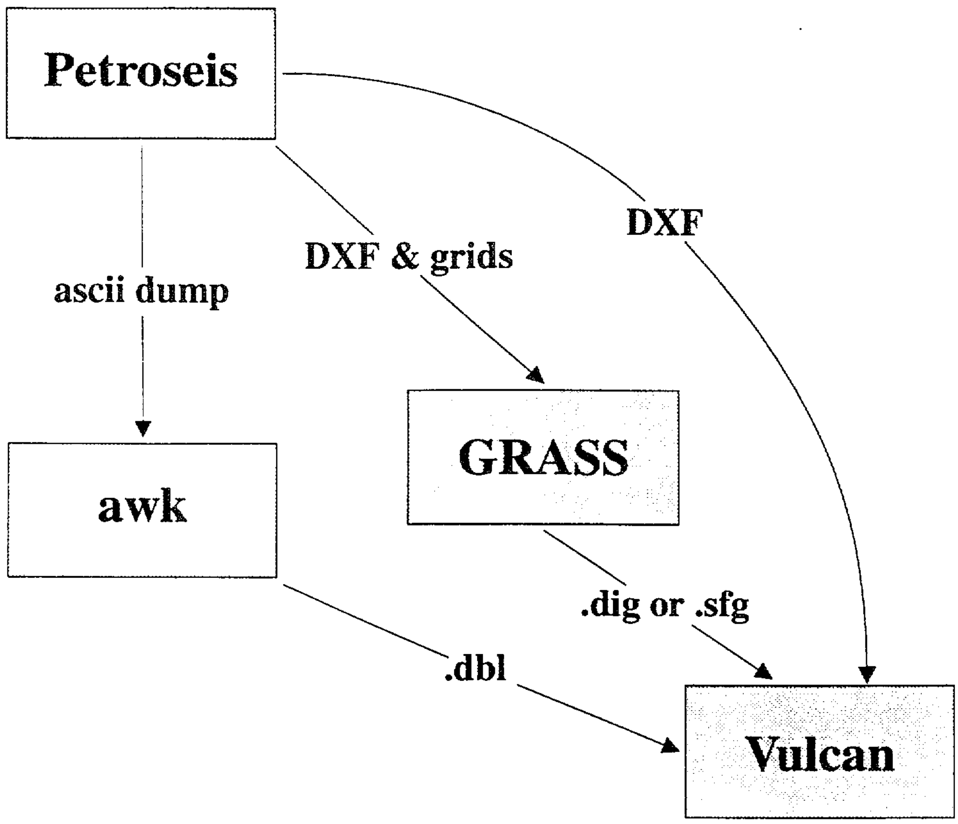
The number of versions of similar filters that have been constructed by different workers is enormous, but in the most general case the construction of N^2 sets of data exchange tools is required to convert between all pairs from N programs. Furthermore, a one-to-one mapping of objects between applications is only possible if they share the same data-model. Clearly a system dependent only on such a suite of specific conversion filters would be difficult to manage.

Standards, data sharing

A more rational system would use a single intermediate standard, so that each application is required to import and export to that format only. For the same N programs only 2N filters (between each program and the exchange standard) are needed. A further attraction of a comprehensive standard is that it may be possible to use that to supply persistency, and thus a common database for our suite of applications. Application-specific versions of the data would then be transient, created "on-the-fly", and the problem of multiple copies and currency could be overcome.

Some proprietary formats have begun to attain the status of de-facto standards, on the basis of the installed software base: for example, most agencies will now supply their data ready for immediate import into Arc/Info. However, this is not a general solution for the reasons given above, and because of the reliance on commercial software from a single supplier. And although Autodesk's DXF has been placed in the public domain, it only supports a very limited range of objects with almost no topology or attributes.

There has been considerable work over the last ten years on developing more comprehensive and open standards, which are just now beginning to have an impact on software. The most important example is probably the Spatial Data Transfer Standard or SDTS (AS/NZS 4270). Defining a fully comprehensive transfer standard is an impossible task, so potential support for various data-models in SDTS is built in through the mechanism of "profiles", and specific implementations also depend on "dictionaries." The current AMIRA sponsored GEO-DATA project is planned to work within this framework.



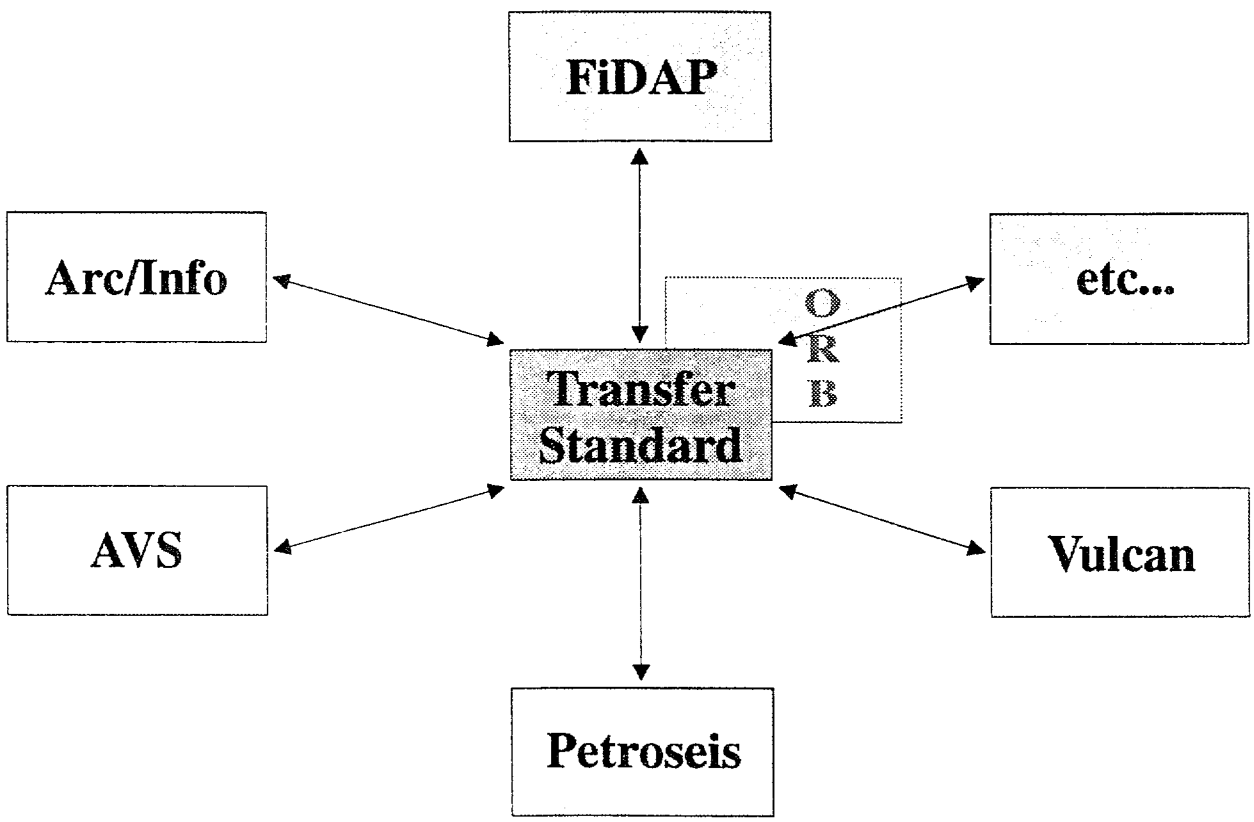


Figure 1. (Top) An example of a set of filters required to transfer data between two applications, Petroseis and Vulcan. (Bottom) The alternative method using an intermediate transfer standard. In the future, the transfer standard might be replaced by an Object Request Broker.

However, because it was driven by and primarily targeted at GIS systems, SDTS is most fully developed for 2D map data. Although there is space in the standard for 3D objects, these are rather generally defined. Independent efforts underway in this area include the European DEEP project for mining information, the POSC consortium's Epicentre model for the petroleum industry, the Canadian SAIF format, and the OGIS research project on general interoperability for spatial information systems. CSIRO Exploration and Mining has also had a project running examining the use of object-oriented methods for constructing a "universal" data model for geoscientific data exchange. This has particular advantages in providing a basis for the construction of software, rather than just data transfer.

However the process of incorporating all the necessary pre-existing models of data into any of these efforts is laborious. Furthermore, since it will be necessary to share the same data between applications with different models, conversion between these, including promotion and demotion, generalisation and refinement operations are required to suit any instance. It is important to realise that the procedures for accomplishing these are generally highly model dependent, and automation may not be possible (Table 2).

Metadata

Sharing information in the ways envisaged here means that metadata (giving an audit trail for the source and quality of data, and also the transformations that have been applied) is critical. Although metadata is a component of SDTS (for example), this aspect of the standard has not been widely implemented. Imposing an effective discipline on the maintenance of metadata is a real challenge.

Furthermore, in the AGCRC much of the information will not be primary observations, but rather "interpretations." The metadata must therefore capture the methods used to generate these "derived-data" so that if either the base observations or the methods are revised, the derived data may be updated. Properly designed, it may be possible to use the metadata to generate a script which could automatically regenerate the derived-data from the source and methods. In other cases the method will not be a rigorous, reproducible algorithm, but the "hunch" of a geologist based on their accumulated experience. Particularly in these circumstances knowledge of this "method" may allow a user to weight the information appropriately before further analysis or modelling. Thus, the links to the observational and model basis must be explicit and available.

Networking

The AGCRC operates from sites in several cities, and information and applications are stored at each of these. An integrated system must therefore include network access to both data and tools.

Fortunately, the basic tools to service this are available now, and are very cost-effective. The WWW connects all computers which are nodes on AARNet/Internet. Configuration only requires installation of Web-browser software (eg Netscape, or Mosaic which is public domain and free) for reading, or Web-server software (versions are also available in the public domain) for publishing. The Universal Resource Locator (URL) addressing scheme finds information on any participating host machine.

We plan to use the WWW extensively, and it will potentially provide the main access mechanism for the 4DGM. The WWW has become a mainstream, but flexible and powerful standard. Aligning our work with this will allow us to take advantage of a much tool development work being carried on world-wide, often placed in the public domain, while minimising risks of technical obsolescence. AGSO's @ngis system is planning to take the same route for much the same reasons, and the synergy between the two systems will be a significant benefit.

However, a particular weaknesses in the WWW is in indexing data. For the AGCRC this will have to be overcome with specific tools, particularly browsers to determine the scope of 4DGM datasets and invoke the transformation of the relevant data from the persistent (database) format to that of the tools. There is a potential role for a GIS system here. Note that the question of access permissions, especially for information that is commercially sensitive, can be solved through the normal methods of passwords, etc. These issues will also be considered as part of @ngis, and we expect to use systems compatible with the solutions determined for that.

Table 2. Examples of model dependent data transformations

Transformation	Methods	Variations & options
station → grid data	interpolation	triangulation, splines, kriging
continuous → categories	classification, quantising	supervised, unsupervised, thresholding
objects →grid	sampling, discretising	cell shapes & dimensions
block model → geophysics	potential field modelling	superposition methods, frequency domain methods
soundings → 3D geometry	seismic/EM/drill-hole interpretation, interpolation	classification methods, interpolation methods
geological history → geometry	geological modelling	Noddy

As well as data, the 4DGM will make tools available. Software using floating licenses may be served over AARNet/Internet, so specialised commercial software may be made available across the AGCRC in a cost-efficient way, with binaries stored and executed locally. This has been successfully trailed between CSIRO Floreat and Nedlands. Even node-locked software can be run via remote X-sessions between trusted server-client pairs. Display performance depends on network speed and congestion, but since processing is carried out on the server, analytical performance may still be high. For example, Vulcan has been run as a remote session on an SGI-Onyx at CSIRO Nedlands from a variety of other workstations.

In these cases the legacy applications run through their native interfaces, so normally only expert users would access the system in this way. However, one strength of the WWW is the ability to provide "friendly" interfaces onto software. The Common Gateway Interface (CGI) protocol together with the "Forms" and "Imagemap" interfaces of the WWW provide a standard mechanism for doing this easily for any software which can be invoked with an ascii command line, or run with instructions on "stdin" or command files. Tools to generate SQL style queries for RDBMS are also available. This interface would make fewer assumptions about the technical skills of the user, except the use of the language of geoscience in describing their queries or models. Typically the results of processes would be written as graphics files, for example, GIF or JPEG for immediate transfer and viewing, or PostScript for downloading and printing, or as animations using the MPEG format.

Note that two projects related to the AGCRC involve specific new software tool development: the AMIRA/AGCRC Noddy project based at Monash, and the GeoEditor project at CSIRO DEM and DIT, so we can expect these to be adapted to the 4DGM environment.
An experimental WWW interface using some of these concepts has been developed (Figure 2). At present this is only operating on a single site, but access to the other AGCRC sites, and then to external users will be opened up as it is developed further.

Summary

The Australian Geodynamics Cooperative Research Centre (AGCRC) is engaged in a substantial new synthesis of the geodynamic history of Australia. This includes both compilation of existing models, and new interpretations of critical areas. Central to the project is the use of computer-based modelling and visualisation techniques. The aim is to capture and present the outcomes of this work in an interactive digital environment, and make this available to the exploration community.

A variety of software will be used to achieve this, including GIS systems for map analysis and data browsing. However, 3D and dynamic modelling tools will play a large role. Various mechanisms for sharing information between different programs are being considered. Access to the information and some of the tools will be via the WorldWideWeb (WWW), in conjunction with AGSO's @ngis system. In this way, a common interface to a loosely linked suite of programs and information constituting the 4DGM can be made available through any AARNet-connected computer running a Web-browser. Distinct to the 4DGM is the fact that much of the information will be "derived-data", so the metadata links to observations and modelling methods will be important.

Acknowledgments - *Many colleagues (too many to name) at CSIRO, Monash University and AGSO have contributed towards the development of the ideas included here. Product names are used here for descriptive purposes only and do not imply endorsement or recommendation for any particular use.*

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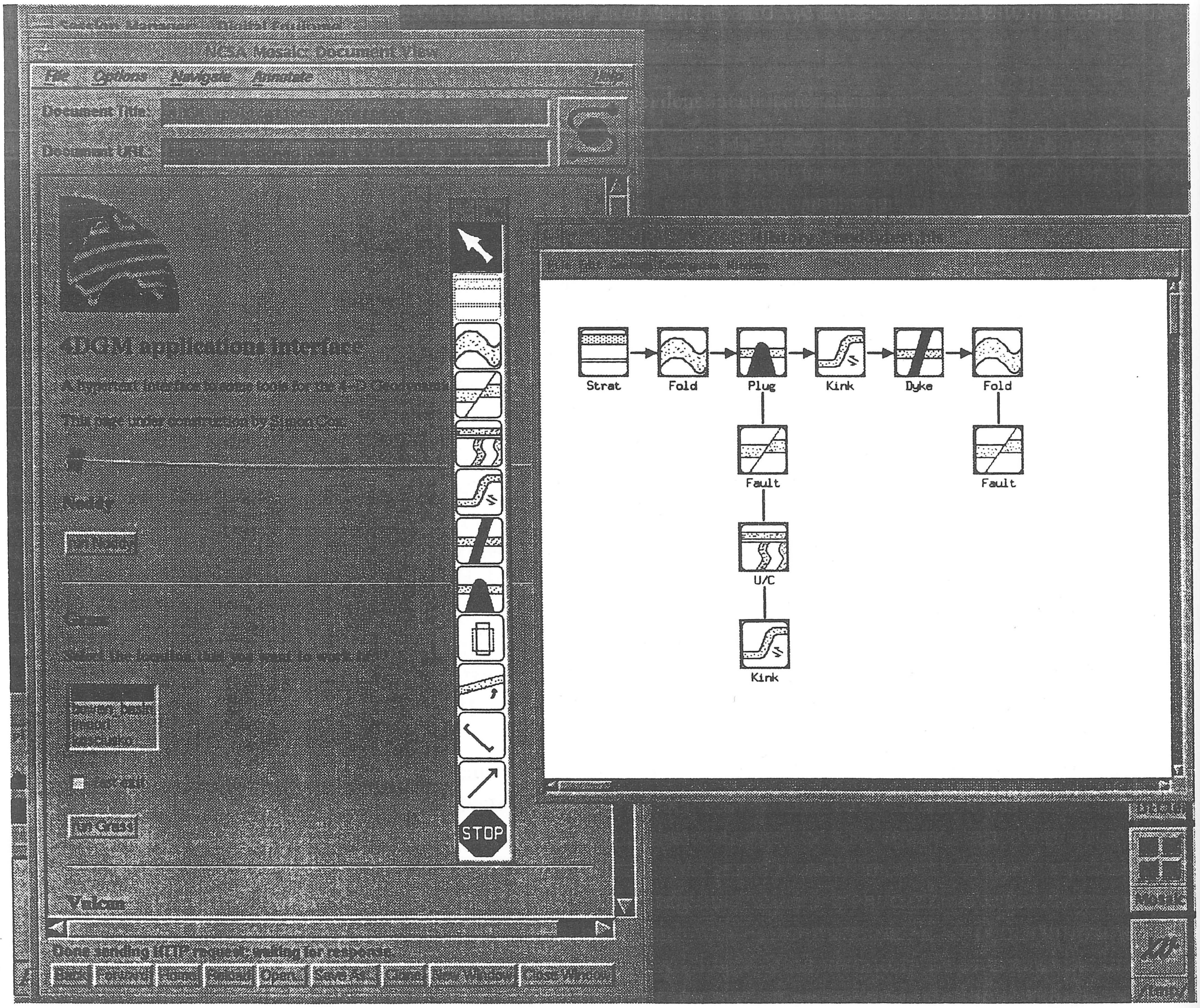

Figure 2. Prototype interface to the AGCRC's Geodynamic Model, using the WorldWideWeb to start a session running the Noddy modelling software.

SIMPLIFYING RELATIONAL GEOLOGICAL DATABASES BY GENERALISATION

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Abstract - Unless database designers are careful, the complexity of geological subjects can result in data models that are too complex to be implemented with available resources. Generalisation involves a search of the logical data model for entities that can be grouped into super-entities occupying single tables in the physical model. Carried out assiduously, generalisation often reduces the number of tables needed by more than a half. Illustrations are taken from the 'rocks' and 'sectholes' parts of AGSO's OZROX field geology database.

Introduction

One of the most difficult problems faced by the designer of geological databases is the sheer complexity of the subject matter. Compared to the business analyst, the geological analyst is faced with a plethora of entities, attributes, dimensions, and units, and by unfamiliar data models very different to those used in well-trodden commercial arenas. In this poorly-known environment, text-book methods of data analysis and modelling easily lead to data models that are too complex to be implemented with the available resources. I know of several geological databases, one of them from earlier in AGSO's database experience, where uncritical application of such methods lead to databases that were far too resource intensive to survive.

Fortunately, there are recognised techniques for reducing the complexity of databases - denormalisation and generalisation (Simsion 1994). Denormalisation, usually done to improve the performance of a database, involves stepping back from an ideal model by reducing the number of tables and increasing data redundancy. Generalisation, which is less well known but often intuitively applied, comprises a search of the logical model for entities that can be combined into super-entities, resulting in fewer tables. Generalisation commonly goes hand in hand with some denormalisation and the introduction of 'null-permitted' fields - but this is not necessarily the case. Since generalisation results in fewer compromises with the logical fabric of a database, this is the technique that should be pursued first when attempting to reduce the complexity of geoscience databases. Although generalisation will often improve the performance of a database, I am primarily concerned with its effect on reducing the work required to implement and maintain geological databases.

The Resources Factor

Compared to the developer of most business databases, the designer of geological databases usually has more limited resources. Geological databases are specialised, used by only a few people, and have less obvious connections to corporate income than databases to do with money, people or stock. Whereas the designer of an inventory, dispatch and invoicing system for a manufacturing company may have a small team and a substantial budget, the geologist-designer often works alone within severe budgetary restraints and his or her databases must also be maintainable. Highly user-friendly screen forms for commercial applications may take months to complete. The geologist-developer does not usually have the time for elaborate applications. They must work within their organisation's resources or their databases will not be viable.

A consequence of the above is that database simplification is more important to geological databases than it is to many commercial systems. Analysts trained in a big business environment can find themselves out of tune with this situation. If they persist in constructing elaborate data models that ignore the resources factor, they will rapidly find themselves out of a job. Designing geological databases to fit within available resources is just as important as good logical design. By applying the database generalisation principles described in this paper, both objectives can generally be achieved.

Logical Spider Webs

Most readers will have seen entity-relationship diagrams that look like spider webs, comprising numerous small boxes with minute lettering for the entities, and connecting lines representing relationships going everywhere. Such diagrams are typically generated by CASE (computer aided software engineering) tools, and are promoted in many textbooks as an essential step in designing relational databases. Fortunately, such diagrams are not produced by CASE tools with reproduction in mind, and this is one reason I am not going to show you one in this paper (except for small subsets). Another reason is that I would not like to embarrass the author of such a monstrosity, although they can be quite decorative as wall ornaments.

Such logical data models are sometimes assumed to be the end point in database design, and the important process of reducing this model to a practical physical database can be downplayed or ignored completely. In geological databases, at least, the designer ignores the second process at his or her own peril. If the logical data model is treated as the physical data model, and all entities made into discrete tables, then the database can end up with more than twice the number of tables it needs to have. In the AGSO example mentioned in the introduction, the original database had 70 tables. By applying the simplification procedures described in this paper, this number was reduced to less than 20 in the current database, while retaining most of the original functionality.

What's Wrong with Many Tables?

Basically, the more tables in a database, the more resources required to develop and maintain the database, and the poorer its performance is likely to be. I sometimes think that the effort required to develop a database increases exponentially with the number of tables. However, the problem is not quite that simple, as the number of data tables and connecting tables has a greater effect than the number of lookup tables. Also, some parts of the total database can be treated as a 'black box', the internal workings of which are of no consequence to the problem at hand. Thus the AGSOREFS bibliographic database (Ryburn & Bond, 1995), although quite complex in itself, can be treated as a single look-up table by other geological databases that refer to it via unique reference IDs. This modular approach to reducing the apparent complexity of databases is widely employed in my National Geoscience Database Development project, which is part of AGSO's National Geoscience Information System (NGIS) program.

The negative effect of too many tables extends particularly to the development of screen forms and reporting programs. Forms and reports that are quickly implemented if they involve just a few tables, become complicated, slow to implement and run, and difficult to maintain with the involvement of more tables. The number of tables has a compounding effect, so that the elimination of just a few tables from the database schema can have a great freeing-up consequence to the development of the database as a whole. Table reduction is an excellent means of reducing workload.

AGSO's OZROX Database

OZROX (formerly the NGMA database, Blewett & Ryburn 1992, Ryburn *et al.* 1993) is AGSO's field geology database, and the hub of a number of other field and laboratory geoscience databases (Ryburn *et al.* 1994). Potentially rather a complex database, the physical structure of OZROX has been kept to seven main data tables, with links to a number of other lookup tables and standards databases. In Figure 1, the main data tables are down the centre, with all validation tables and databases down either side.

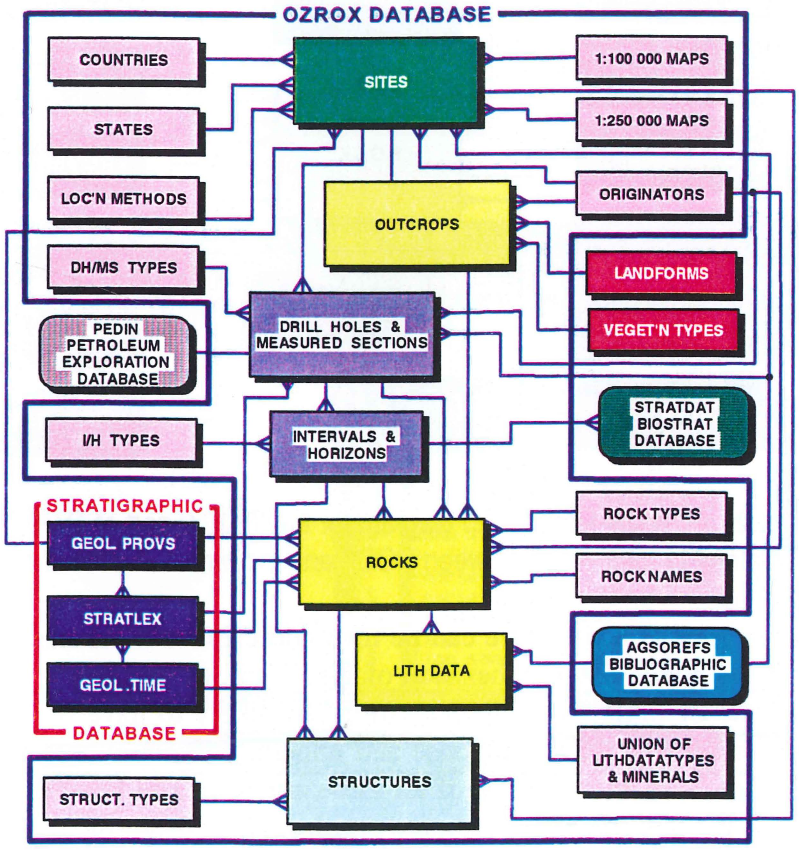


Fig. 1. A table-relationship diagram showing the physical structure of the OZROX database. Crows feet mark the 'many' end of many-to-one links.

Note that Fig. 1 is a table-relationship diagram, not an entity-relationship diagram, and that all tables are named in the plural. In my convention, singular names are reserved for entities in the logical model, while plural names are for tables in the physical model. When it comes to generalisation it is not a good idea to confuse entities with tables.

OZROX has five main data categories, namely geographic location (site) information, outcrop observations, drill hole and measured section data, lithology and rock sample data, and structural geology observations. Whereas sites, outcrops and structures are single data tables, measured sections and drill holes, and rocks require several tables to represent the relationships inherent in the data themselves, and it is these that I will use as illustrations of how the generalisation process can be applied to geological databases.

Data Structures for 'Rocks'

The OZROX data structures for 'rocks' are designed to encompass both lithological observations and rock samples at a site. So, generalisation immediately comes into play with the recognition that two entities - LITHOLOGY and SAMPLE - have been shoe-horned into the one ROCK super-entity. However, the only obvious consequence of this is that the Sample ID attribute will have a null value if a sample was not collected, and for our purposes we can treat ROCK as an entity. No, the real saving comes into play with the numerous related entities in the following logical model:

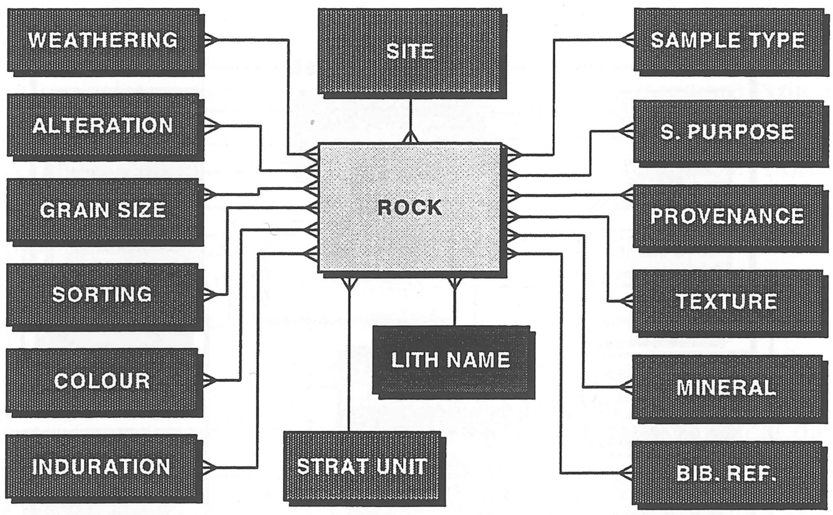


Fig. 2. An entity-relationship diagram for the 'ROCK' part of OZROX. Note the many-to-many links between ROCK and the outer columns of entities.

For any given rock at a site there can be many descriptive attributes, such as colour and texture, and the boxes down either side of Fig. 2 are just a subset of possible attributes. Although some of these, such as induration, are likely to have only one value for any given rock, others like sample purpose and mineral will commonly have several values. Overall, though, it is an advantage if all these attributes can be multi-valued, and in the above model they are treated as separate entities with many-to-many relationships to the rock entity. Lithological name and stratigraphic unit, on the other hand, should have just one value for any given rock, so the relationship in these cases is one-to-many.

To try to implement the above logical model as a physical model would be a disaster, as the physical model would require intermediate tables between the ROCKS table and the tables for all the outer entities in Fig 2. Fortunately, this logical model can be highly generalised, with nearly all the outer entities lumped into the one LITHDATATYPES validation (authority) table, and all the intermediate tables required by the many-to-many relationships generalised into a LITHDATA table - also referred to by me as an 'extendable attributes table'. The physical model adopted by OZROX is as follows:

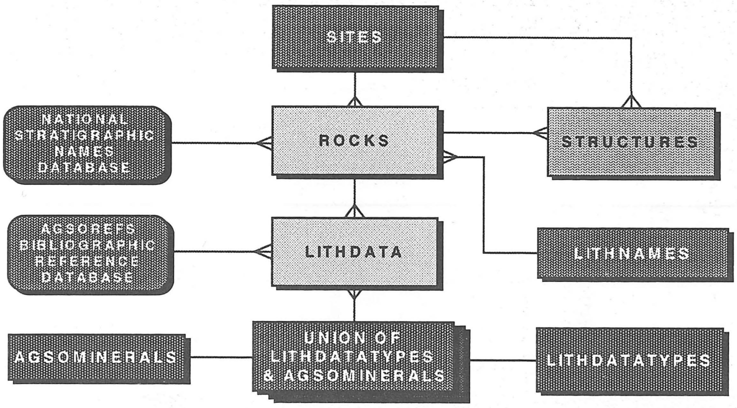


Fig. 3. A table-relationship diagram showing the physical structure of the ROCKS-related parts of the OZROX database.

Mineral names were not included in the LITHDATATYPES table, as there are over 800 of them, and an unpolluted table of mineral names is also required by AGSO's petrography (PETROG) and mineral deposits (OZMIN) databases. However, a union allows the AGSOMINERALS and LITHDATATYPES tables to be viewed by LITHDATA as if it were a single validation table. The LITHDATATYPES table looks like this when seen from the corresponding screen form:

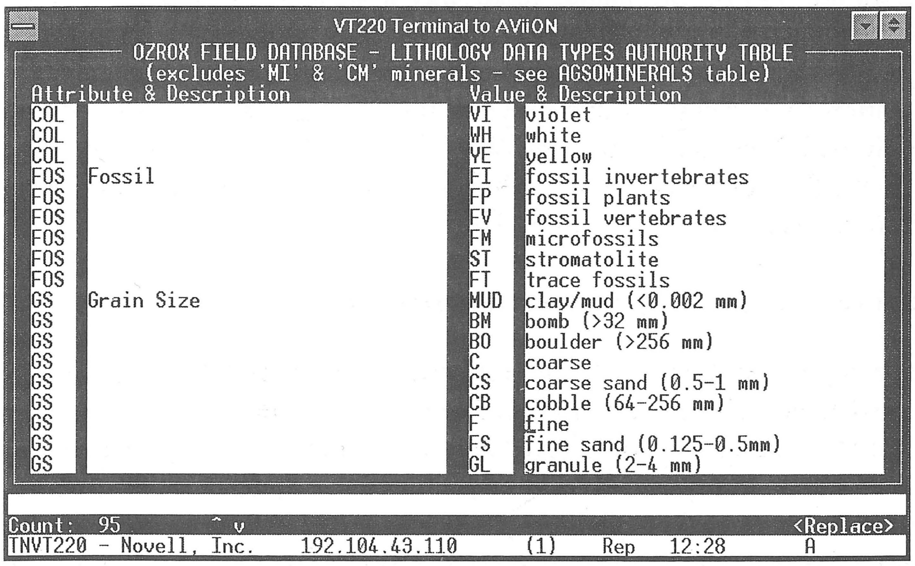


Fig. 4. The screen form corresponding to the LITHDATATYPES validation table, showing colour, fossil and grain-size attributes with permissible values.

The main OZROX form used to enter and query data in the ROCKS and LITHDATA tables is shown in Fig. 5. This form also covers the STRUCTURES table, as the link between lithology, stratigraphic unit and structure is an important one. Note that the second block in this form effectively supplies extendable attributes to the ROCKS table, with as many 'attributes' added to a rock record as may be needed. More than one record of the same type, eg, 'Magnetic Susceptibility', can be entered. All 'attributes' and 'values' entered here are validated against the above LITHDATATYPES table. If new descriptive 'attributes' and 'values' are required they can be added without altering the structure of the database.

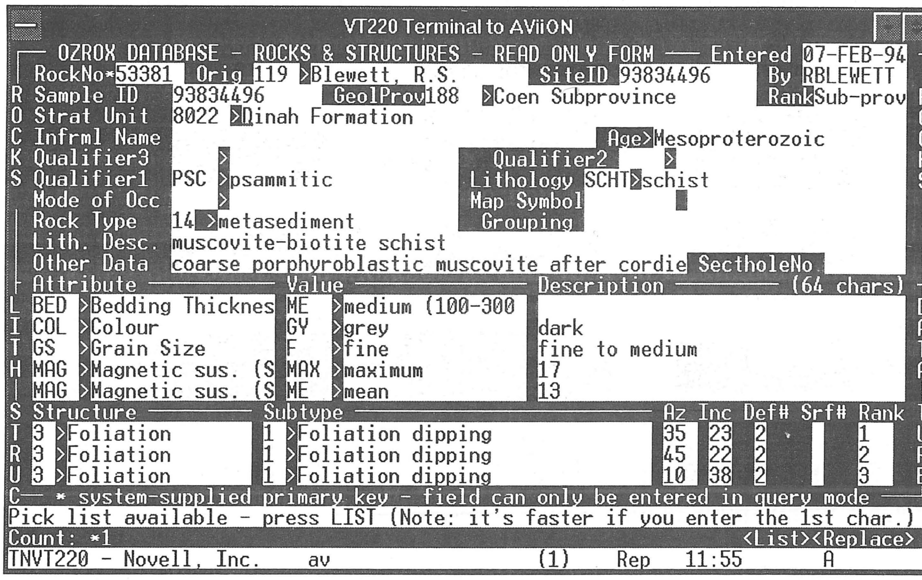


Fig. 5. The Rocks and Structures screen form corresponding to the ROCKS, LITHDATA and STRUCTURES tables in the OZROX database.

Generalisation has also been applied to the placement of pointers in the LITHDATA table to bibliographic references in the AGSOREFS corporate bibliographic database (Ryburn & Bond, 1995). Originally, there was a separate ROCKREFS table linking ROCKS to references in AGSOREFS. However a 'REF' record can now be inserted into the LITHDATA table, and a pointer to the reference placed in the description field (Fig. 5). A validation trigger ensures that only the IDs of existing references can be entered and the AGSOREFS database can be invoked with the 'list' function when the cursor is in the comments field of a REF record. This tactic has eliminated one table and one form for a function that is not used very often.

Data Structures for Measured Sections and Drill Holes

The linear geological logs obtained from measured sections and drill holes are essentially the same, so I have coined the term 'SECTHOLE' for the super-entity covering both measured sections and drill holes (also costeans, adits, etc). In drill holes the log usually starts at ground level and is measured going down the sequence. In measured sections the log starts at one end and progresses up or down the sequence. In either case, intervals and horizons are measured in metres distance from an origin attached to a SITE record.

The ability to handle 'secthole' logs is a recent addition to OZROX. I wanted to preserve the tables already in existence for outcrop-associated rocks, structures and stratigraphic units for the corresponding entities in measured sections and drill holes. The following logical model (Fig 6) does this, and more:

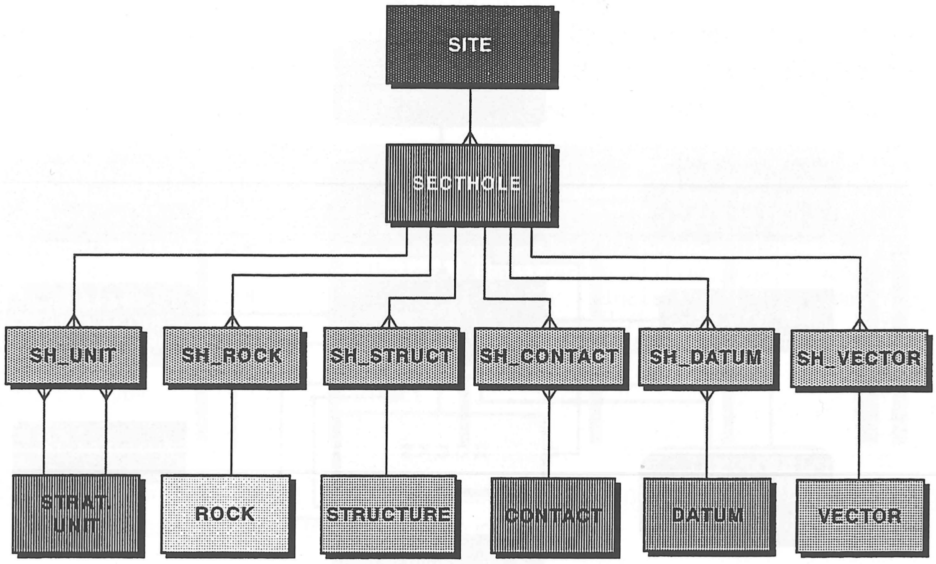


Fig. 6. An entity-relationship diagram for the measured sections and drill holes ('SECTHOLE') part of the OZROX database.

The SECTHOLE entity is for the 'header' information on each measured section or drill hole (see Fig. 8). The row of six boxes along the bottom of the diagram are mainly entities that were already in OZROX or other databases, although 'CONTACT' and 'VECTOR' are new entities. The six intermediate entities between SECTHOLE and the bottom entities record the along-section or down-hole distances of intervals and horizons associated with the bottom entities. The ROCK entity, which describes lithologies and rock samples requires two distances to define an interval of finite thickness. The other entities refer to horizons with only distance required. In the above model, many-to-one links are needed to STRAT. UNIT, CONTACT, and DATUM, while the other links are one-to-one. The reason two links are shown to STRAT. UNIT, is that the SH_UNIT entity is for the boundaries between two units. DATUM refers to time horizons in the STRATDAT Biostratigraphy Database, and CONTACT refers to various types of contact between lithologies, such as conformable contacts, faults, unconformities, and intrusive contacts. The VECTOR entity is for recording the zigzag path of some measured section, or the locus of drill holes that are not straight.

If the above logical model were to be implemented as a physical model, several screen forms would be required to handle the data, or alternatively, one form extending to several screens. However, I have grouped all the intermediate entities (with 'SH_' prefixes) into a super-entity called 'INTERIZONS', for intervals and horizons. This results in the physical model shown in Fig. 7, which permits all the data for a 'secthole' to be shown on the one screen, and in order of distance from the origin (Fig. 8).

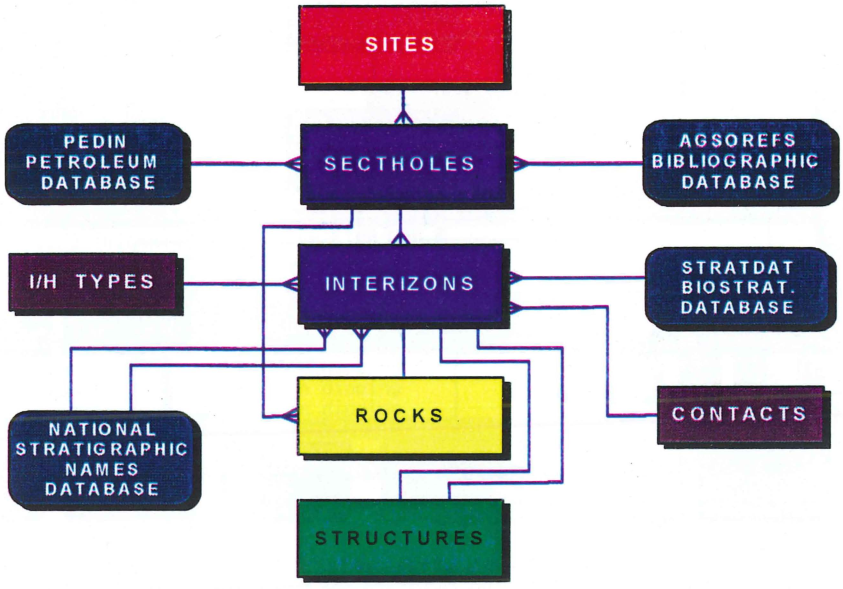
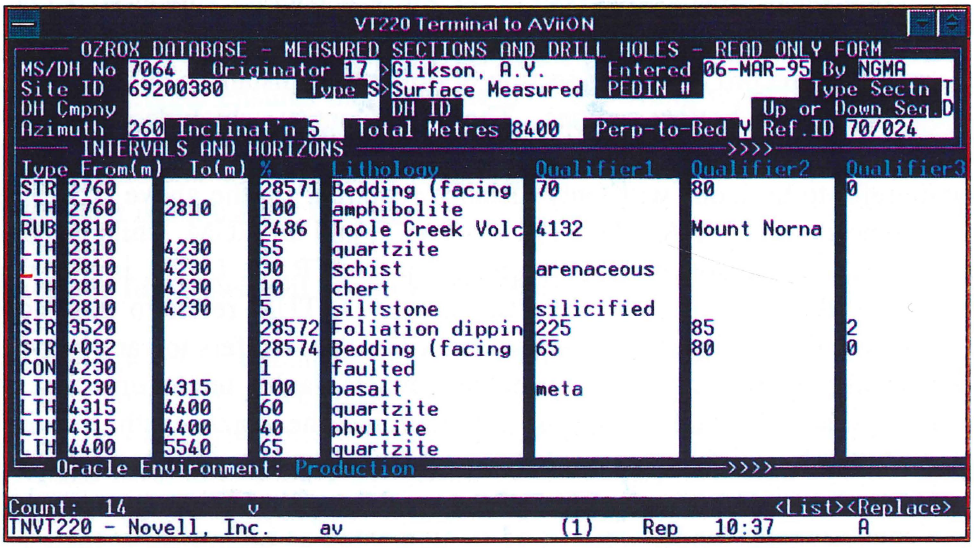


Fig. 7. Table-relationship diagram showing the physical structure of the measured sections and drill holes part of the OZROX database.



VT220 Terminal to AViiON

OZROX DATABASE - MEASURED SECTIONS AND DRILL HOLES - READ ONLY FORM

MS/DH No 7064 Originator 17 >Glikson, A.Y. Entered 06-MAR-95 By NGMA
Site ID 69200380 Type S>Surface Measured PEDIN # Type Sectn T
DH Cmpny DH ID Up or Down Seq D
Azimuth 260 Inclinat'n 5 Total Metres 8400 Perp-to-Bed Y Ref.ID 70/024

INTERVALS AND HORIZONS >>>>

Type	From(m)	To(m)	%	Lithology	Qualifier1	Qualifier2	Qualifier3
STR	2760		28571	Bedding (facing	70	80	0
LTH	2760	2810	100	amphibolite			
RUB	2810		2486	Toole Creek Volc	4132	Mount Norna	
LTH	2810	4230	55	quartzite			
LTH	2810	4230	30	schist	arenaceous		
LTH	2810	4230	10	chert			
LTH	2810	4230	5	siltstone	silicified		
STR	3520		28572	Foliation dippin	225	85	2
STR	4032		28574	Bedding (facing	65	80	0
CON	4230		1	faulted			
LTH	4230	4315	100	basalt	meta		
LTH	4315	4400	60	quartzite			
LTH	4315	4400	40	phyllite			
LTH	4400	5540	65	quartzite			

Oracle Environment: Production >>>>

Count: 14 v <List><Replace>
TNVT220 - Novell, Inc. av (1) Rep 10:37 A

Fig. 8. The screen form for measured-section and drill-hole data. Note that column headings in the intervals and horizons part of the form change as the cursor is moved up and down the columns - depending on record type.

The columnar part of the screen form in Fig. 8 corresponds with the INTERIZONS table shown in Fig. 7. All data in this part of the form are ordered according to distance along-section or down-hole, and the records here can be scrolled to view the entire log. Only the data in the first four columns are actually stored in the INTERIZONS table - the remaining information is displayed indirectly from tables such as ROCKS and STRUCTURES. Pointers to the relevant records in those tables are what is stored in the INTERIZONS table. However, there is also a comment field that can be seen by scrolling the form horizontally to the right. At the appropriate point, when entering data into this form, you are automatically transferred to forms for entering lithology, structure, etc. As can be seen in Fig. 8, a given interval can have several different lithologies with assigned percentage values. The six types of records that can currently be entered into the INTERIZONS table, and their corresponding column headings, are shown below in Fig. 9. Although all these different record types share the one INTERIZONS table, the logical model could easily be emulated by creating a separate view for each entity.

VT220 Terminal to AViiON

OZROX DATABASE - LOOKUP TABLE FOR INTERVAL/HORIZON RECORD TYPES ->>>>

Record Type		Pct Header	Lth Header	Q1 Header	Q2 Header	Q3 Header	Pt
LTH	Lithology	%	Lithology	Qualifier1	Qualifier2	Qualifier3	N
STR	Structure	Str#	Struc.Type	Azimuth	Inclin.	Generation	Y
STD	STRATDAT Datum	.	Pick Type	Datum Name	Hi/Low	Pref/Alt	Y
RUB	RockUnitBoundary	O Strat#	Overlying	U Strat#	Underlying	.	Y
SVY	Survey	Seq	Azimuth	Inclinat'n	.	.	Y
CON	Contact type	.	Contact	.	.	.	Y

Fig. 9. A screen form for the 'I/H_TYPES' table, with the interval and horizon record types and column headings used in the form shown in Fig 8.

The 'Survey' and 'STRATDAT Datum' record types in Fig. 9 are not represented in the data shown in Fig 8. The Survey record type allows vectors at any point along a measured section or drill hole, thus providing a linear survey of irregular sectholes. In yet another bit of generalisation, the VECTOR entity has been added to the existing STRUCTURES and STRUCTYPES tables as a special structure type. The STRATDAT Datum record type is a pointer to a horizon in the STRATDAT biostratigraphic database, typically a foram zone boundary or some other time-related datum.

Conclusions

To convert complex logical models for geological databases into practical systems implemented on time and within budget, it is often necessary to employ generalisation in going from the logical to the physical model. Generalisation is to be preferred over denormalisation, as it involves fewer compromises with the theoretical data structure. Not only does the generalisation process lead to fewer tables and more adaptable database structures, it also results in more user-friendly screen forms.

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LEGAL REGIMES IN ACCESS TO GEOGRAPHIC INFORMATION

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Abstract: A traditional view of information is one of ownership and control - both of which imply restrictions to access. A *laissez-faire* view highlights open access and free dissemination of information. Each of these reflect particular institutional settings and policies in place to protect 'public goods'. This paper explores legal regimes governing access to geographic information collected by public agencies. Cross-national comparisons are made to give principles and practices and highlight the legal-policy responses. The legal issues emerging from these different regimes are discussed including an outline of policy implications.

Introduction

A traditional view of information is one of ownership and control - both of which imply restrictions to access. A *laissez-faire* view highlights open access and free dissemination of information. Each of these views reflects a particular institutional setting and the kinds of policy in place to protect 'public goods'. Whatever view is adopted, the importance of access to information cannot be overstated. Greater access to information enables a user to become more autonomous, flexible, innovative and efficient in undertaking tasks. All these elements should enhance policy formulation and decision-making (Epstein 1991: 491). Information connotes the power of selection or choice and the choice among scarce resources is a central question of economics (Mackaay 1982). The lack of information impairs choice, so that decisions are made in uncertainty. Data and information serve as an antidote to uncertainty.

The purpose of this paper is to explore the legal regimes governing access to geographic information collected by public agencies. This will be achieved through a cross-national comparison of practices in the dissemination of geographic information. The principles and practices will be compared as well as the legal-policy responses to particular issues being raised by the new information technology. Current trends and possible future directions may provide guidance to future international regimes governing the dissemination of geographic information.

There are three parts in this paper. In part one there is a discussion of the value of access to geographic information. Then in part two the various legal regimes governing access to geographic information principally in common law countries will be examined and compared. In part three the legal issues emerging from the different regimes are discussed before a concluding section which outlines some policy implications.

I. Access to Geographic Information

In this section the 'value' of access to geographic information is highlighted in terms firstly of information as power. this is followed by a discussion of other values including democratic rights, the development of GISs, cost recovery and ownership issues.

INFORMATION AND POWER

Information, it has been said represents power of various kinds. For the ordinary citizen, information can represent the power to improve their livelihood and personal circumstances which can make a difference in their private lives. Access to information can also make a person better informed - especially about what governments are doing and how these may impinge on them. As well at a global scale such informed citizens become more aware of other problems such as global warming, desertification and rapid population growth.

The information technology revolution as manifest in GIS technology has opened a whole new ball game but without a set of rules to govern the game. GIS technology is double-edged as it provides instant access to a vast amount of data but at the same time opens the way to abuse, misinformation, and invasion of privacy on a far greater scale than was possible previously. Individuals who control that information resource exercise substantial power. But where there is power there should be accountability, although such legal and ethical guidelines are as yet unframed and unresolved (Aronoff 1989: 284ff).

Geographical information has many potential uses in helping to deal with different problems of the environment, urban growth, resource management and so on. In addition to such economic uses, there is also the national security aspect and its various strategic implications. It is not surprising that in many parts of the developing world, especially in Asia, it may be impossible for private citizens to acquire topographic maps for private use on grounds of posing threats to national security. The difficulty also extends even among government agencies in such countries. In these countries the security value of maps may be far more important than its commercial value. The dilemma here is that in the data gathering process, citizens are expected to surrender their individual rights and resources in the common interest to enable the state to carry out its state functions. When these views are transported in time and space to the developed world the problem is not one of security in a strategic sense. Rather the problem becomes one of trading off the protection of private interests as against making information available to the public, the use by public agencies of such public information to fulfil their respective legislative mandates and commercial enterprises to add value to the information for further sale in the information market-place. Such trade-offs have yet to be addressed by both academics and the courts in terms of balancing the relative needs of various parties in order to produce a rational objective policy on the legal limits to data access. As GIS technology matures, the question of access will assume even greater importance in how geographic data are handled by public agencies.

DEMOCRATIC RIGHTS

The rights of the private taxpayer extends to knowing what public officials do and accountability in the functions of government. Access to government information, it may be argued, will provide some measure of ensuring that public officials are undertaking their respective tasks in a proper manner. Another view is that data and information collected by government agencies should also rightly 'belong' to the community given that the data have been collected and funded indirectly by the tax payers. The provision of 'public' data to all requests therefore should be on the basis of marginal costs; and where the costs refer only to the costs of reproduction. Both of these viewpoints above may easily be countered in institutional settings in which access to government information may be denied on grounds of confidentiality, privacy and national security. Such institutional settings may be seen to curb rights of access and indirectly democratic rights. Where a balance is struck between access and non-access may fall on one's ability and willingness to pay. While this may lead to an 'information-rich' and an 'information-poor' categorisation of that democratic society, it is nevertheless one of the unsavoury aspects of democracy in a capitalist economy. Ideally there should be a 'free market' in ideas that comes about from an unconstrained availability of information.

DEVELOPMENT OF GISs

GIS development and applications are becoming integrated with the overall information management operations of many government agencies. After initial GIS development funding, there is the need to develop approaches for the continued operation, maintenance and upgrading of the system. There is a large potential market for GIS products although different regimes have different institutional frameworks which do not totally support GIS developments. This will hamper the meeting of the potential demand for GIS products and services. In this respect resource allocation, cooperative funding (public and private), user fees, other access rights and operating costs must be examined with a view towards generating revenues. The revenues derived from the sale of GIS products and services may thus be seen as a way of further developing the information system as well as to keep abreast of latest developments and changes. Without user access fees a GIS will be unlikely to grow and develop with the new technology.

COST RECOVERY

The principal objective with cost recovery is that the provider of information maintains sufficient control over access to requests and to avoid the expense of having to meet an as yet undetermined demand. It also has the effect of establishing an effective method to offset costs of developing, establishing, operating and maintaining a data collection system as well as distributing the data. Such a system may be used to perform a government agency's statutory functions in conjunction with a recovery of costs when the data and services are provided to private and commercial users. The construction of a GIS database represents a very high investment of public money. However, this represents a very low overhead source of information to the private sector 'value-added' information industry. Somewhere along this continuum therefore there is a point where the government agency's interests and that of the private industry will balance, and at this point the price will reflect what the market will bear and the value of the cost recovery.

OWNERSHIP ISSUES

Who owns the information that is in the custody of public agencies raises some very interesting issues of law and economics. It is clear that there can be no access to information if the 'owners' do not wish to share it or to allow it. There may be commercial values attached to the information which are determined by the market-place either directly or indirectly. It is increasingly being recognised that the creation (or destruction of wealth) has more to do with information than with material manipulation in manufacturing and industrial output. At the flick of a switch or tap on the key-board of a computer huge assets may be bought or sold, won or lost on the financial markets of the world. Access to information is thus important although tempered by ownership considerations. Where the information are under the control of custodians, especially publicly-held information, access may either be enhanced or further reduced. A custodian may licence the use of data for particular purposes. The custodian, on the other hand, may refuse to supply the data where the usage is deemed inappropriate. The importance of ownership and access therefore reside in whether the policy is one of cost-recovery or simply a matter of licensing to ensure that data wastage is minimised. The issue thus is reduced to the administrative processes in place for the distribution and the making available of the data.

In sum, access to geographic information can have three aspects to it. The access may be at a governmental level (that is, intra-agency and between agencies), access at the scientific and professional level including teaching and research institutions and access to information at a commercial level. At each of these levels the information acquire a public, private and commercial value which to a lesser or greater degree describe the way access is to be granted or withheld. Thus, in order to appreciate the difference in access one needs to understand the institutional setting governing the use of public information. This is discussed next.

II. Regimes in Information Access

This section could more correctly be subtitled regimes and rationales for access to public information sources. More specifically, it explores the various laws and regulations governing access to geographic information or as a wit would have it - Government Information Systems. Because various institutional structures exist, the various models are first described and then compared to highlight cross-jurisdictional differences.

AUSTRALIA

In Australia there is prevailing a regime in which public data are 'owned' and are in the hands of 'custodians'. The idea of custodianship in the Australasian context is that information is owned by the corporate entity and not the individual parts comprising the entity, and that information collected, produced and maintained by the part is available to the whole. At the governmental level therefore, the data are 'owned' by the government on behalf of the community and that individual government agencies are custodians of particular data sets (Clarke 1991; ALIC 1990a). Basically, the data are licensed for particular uses and where the intended uses are deemed inappropriate the custodian may refuse to supply the data.

The ownership of data presently held by Commonwealth and State agencies is not an issue. This is because the Australian taxpayer has funded the majority of data collection expenses and therefore owns it. Most agencies consider the data and information as valuable corporate resources. In order to maintain its value these data resources have to be constantly updated and made relevant for particular uses. As in other enterprises, the timely availability of data can be crucial to informed decision-making. To finance some of its data collection activities government agencies put in place cost recovery policies despite having to balance such motives against its 'community service obligations'. Some strategies result in cross-subsidising the public good aspects of its activities from its cost recoverable activities, while others may simply neglect its public good obligations.

In a paper on the use and sharing of natural resource information between Commonwealth and State/Territory agencies within Australia, Pahl (1991) reported on the use of the Memorandum of Understanding (MOU) which sets out the broad principles governing access to and the sharing of information. Such an arrangement also spells out cost recovery strategies and how the custodianship of data will be managed. The specific contents of the MOU relates to the supply of data, ownership, use and special custodial requirements of the data, disclosure to third parties, the form the data are provided and access to the data by a government agency. However, the overly legalistic construction of the MOU has meant that the model subsequently used became more a statement of intent by each of the parties and therefore not legally enforceable. The statement of intent is simply to provide a framework to facilitate the exchange of data. Also it was observed that for such cooperative ventures to succeed it is imperative that all parties perceive 'ownership' of the final product.

As part of the policy in the sharing of geographic information in the ACT, the Cooperative GIS (COGIS) scheme has brought together all government agencies and public utilities whereby almost all spatially referenced data can now be shared. The protocols for transferring data, formats and other details have now been developed and used to enhance the work of COGIS. Duplication of data has been avoided and the standardisation of data formats has been achieved (Hyde pers. comm. 1994).

The Australian Bureau of Statistics (ABS) has packaged its demographic data obtained from the Census of Population in a CD ROM mapping package beginning with CDATA86 and followed by CDATA91. The mapping package was SUPERMAP™ which permitted the mapping of population data onto maps using census boundaries at various scales. In the 1991 Census of Population, the data are provided in both the SUPERMAP™ format as well as a true GIS format through MapInfo®. The latter now permits mapping demographic data at a 'street level'. This new development has now added to the versatility of the CDATA91 format product because the data are now imported directly into GIS analysis without the need for further processing.

NEW ZEALAND

The issue of geographic information and resource data is governed by the NZ *Resource Management Act*, 1991 and the *Survey Act*, 1986. The former provides a 'framework' for sustainable management where a local authority has the duty to "gather information and monitor" (s.31) and to keep 'reasonably available' information relevant to the function they are responsible for (s.34). In the latter, the mandate is "to produce and maintain topographic maps and digital records". Within these limits government agencies operate in a similar manner to their counterparts in Australia. This is because New Zealand is a participant in the Australasian Land Information Council (ANZLIC).

UK AND EUROPE

In the UK the Ordnance Survey (OS) is organised as a Crown Corporation. With its executive agency status it is able to establish a price for its products and services, and to set the price at what the market will bear. The statutory mandate of the OS was to produce topographic maps. While it produced large, medium and small-scale digital maps there was a growing need for large-scale data and the OS was unable to keep up with demand in this area. This was also hampered by the OSs insistence on very fine details and high-level accuracy in the feature codes used. However, in the 1990s, any organisation in Britain can produce a large-scale map to a defined and agreed standard of accuracy of feature coding for insertion into the national topographic database. As an extension to this idea, and to encourage the wider distribution of the data the government established the Tradeable Information Initiative. Under this scheme government departments are actively encouraged to trade data for profit and in turn underwrite major investments in equipment and to finance their other cognate activities.

In September 1980, the OECD published *Guidelines on the protection of privacy and transborder flows of personal data* of which Australia is a signatory. The Guidelines recommended that member countries take four steps to advance the free flow of information and to avoid the creation of unjustified obstacles to the development of economic and social relations among member countries:

- to take into account their domestic legislation and the principles concerning the protection of privacy and individual liberties set forth in the Guidelines
- to endeavour to remove or to avoid creating, in the name of privacy protection, unjustified obstacles to transborder flows of personal data
- to cooperate in the implementation of the Guidelines, and
- to agree on specific procedures consultation and cooperation for the application of the Guidelines.

Then in 1985, there was an OECD *Declaration on Transborder Data Flows*. The Declaration expressed the wish to promote access to information, to avoid the creation of unjustified barriers to the exchange of information, and to develop common approaches and consultative mechanisms to ensure 'harmonised solutions' to issues relating to transborder data flows.

UNITED STATES OF AMERICA

In the US the regime is one in which the Federal and State open records laws provide a right to citizens to be informed about government activities. The First Amendment to the US Constitution is founded on the belief that a democracy cannot function unless a people are permitted to know what their government is up to. To this end regulations are in place to support a broad policy of government disclosure, that is, if the information is held by an agency and it is determined to be an agency record then it must be disclosed to any person requesting it unless it falls within any one of the nine narrowly drawn exceptions in the *Freedom of Information Act 1966*. Within a GIS context, a private citizen may acquire an entire database produced by a US government agency, typically at the cost of duplication. State open records laws also require custodians to provide records upon request within three working days (Archer 1989: 1575).

Within the parameters of the Open Records regime, Onsrud (1992) has written a paper on the need for cost recovery for publicly held geographic information. The distribution of GIS products and services should be cost recovered on the basis that these are similar to the costs of operating schools and maintaining streets. So even though GIS data has been acquired at tax payer expense and therefore should be free to anyone who has an interest in them, the counter-argument is that it takes additional time and expense to provide such a public service. It had also been argued that the government agency should recover marginal costs that are necessary to respond to citizen requests. This includes staff time, pro-rated to hardware and software maintenance costs as well as clerical time to process requests. Onsrud has gone further and argued that an agency could also recover greater than marginal costs. This subscribes to the view that the GIS can be turned into a revenue generator. In protecting government investments in commercially valuable products the custodianship and public trust argument is used. Here the idea is that the data are not owned by individual government agencies but rather as custodians for the state and held in trust for the benefit of the entire public. Any *trust corpus* may not be given away or sold.

The US Geological Survey (USGS) is limited by law which prohibits the exclusive control by the US of government works, except by rare statutory exemption. US law prohibits reproduction and sale by others at a price lower than that set by the government from the original purchaser. Also the US *Copyright Act 1976* protects against copying, but only of the copyrightable elements in the work. The copyrightable elements are the expressions of an idea, not the idea itself. The ideas in the work are in the public domain and may be taken freely even by copying. There are also provisions in the *Copyright Act 1976* that precludes copyright protection for anything in the public domain.

In the US there seems to be a growing tendency by local governments to move away from the idea of geographic information as a 'public good' towards one where there is a more open and widespread selling of geographic information products and services (Dansby 1992). The question however is whether the public interest will be best served by allowing governments to charge for GIS data, thereby allowing more governments the ability to afford to continue to develop geographic information databases (Rhind 1992, Onsrud 1992b). The alternative, of course is to persist with the open records approach to serve the public interest needs by encouraging the flow of information into the commercial sector (Onsrud 1992a). Such a trend towards data sales is also supported by the Information Industry Association of America which seeks to promote an open access policy for raw data. But the peak body also advocates that all direct beneficiaries of access should bear a fair share of the fixed and operating costs of maintaining such public data banks (Antenucci 1991: 238). One important consideration, of course, is that if a government agency were to sell information products and services, government immunity is not assured and the liability to exposure will be difficult to define (Archer 1989: 1575). In addition, the move towards using the information highway through the creation of a national information infrastructure will allow citizens more access to acquire and to use geographic information (Lehman & Brown 1994).

III. Some Legal Issues

The discussion of the purchase, sale and ownership of public geographic information also highlights that there is a grey area that requires further illumination. The question of legal liability, for example is a subject of much interest to the GIS community. Users and developers of GIS would be much less apprehensive if they knew where liability resides. Thus, those who have been contracted to provide data or those offering data for sale should be responsible for some level of competence in performing their tasks and that the product delivered has some measure of fitness for purpose. If parties suffer loss because of mistakes which a data provider should not have made, then the common law of torts suggests that they should bear some responsibility for the damage incurred. But information databases are a different type of good in that there can be no general purpose database that can satisfy all potential purposes and uses. The same may be said of the accuracy requirements of the data for most purposes. Inevitably, there would be errors and mistakes in the database. But who is ultimately responsible could be a difficult question to answer. This is because, it is to be noted, that GIS is about information and in legal analysis has not been treated as a commodity especially when the government is the source. The difficulty arises in deciding when raw data has been transformed into information and if so, what is its value. Are data and information to be treated similarly as public records or does the former merely represent the traditional 'field' notes' of field workers?

The common law holds that data providers and users should be liable only for those damages that they had a duty to prevent. In order to establish this duty and obligation, one would need to look towards the theories of contract or negligence (tort) law. But there are other theories of liability including those of open records statutes, privacy statutes, anti-trust statutes, product liability and breach of warranty and civil rights statutes. While disclaimers may help avert most product liability claims, there are other legal devices which provide a measure of protection including sovereign immunity, the application of waivers to particular agencies and particular activities. For instance, if an undertaking by a public agency is discretionary then liability may be found. This would also be the case where the conduct of the government agency is such as to encourage a justified reliance on the adequacy of performance. Incorrect information entered into a GIS database may give rise to a claim in negligence.

There is however, an underlying dimension which requires further study. American society is reputedly known to be a litigious one. It may be argued that governments in the US may have adopted an open records policy mainly to forestall the amount and degree of litigation if information products are sold. By practically giving away databases and information on an 'as is basis' no liability may be found because of a lack of privity either in contract or in tort and hence little possibility of litigation arising.

The legal issues therefore are not only in terms of the quality of the data itself but in the use of that data. These may include:

- the legal responsibilities for the use, misuse and unintended uses of geographic information
- the infringement of personal liberties (for example, the use of EFTPOS records to profile persons and their shopping and eating habits)
- the issues of copyright and intellectual property rights so that the easy access to information results in some form of derived datasets and the profits that accrue from value adding to the data
- decisions made on the basis of inaccurate data or the misuse of accurate information
- misunderstanding the nature of the data. For example, data produced by an agency for use by others who are unaware of data error attributes, what the information represents and what computations have been made with the data.

Some liability scenarios in the case of maps has been described in Epstein (1991: 499). Maps may contain errors, may be poorly designed and may be used in inappropriate and ways intended by the map maker. Three issues that have been the subject of litigation include:

- errors and omissions in represented locations
- error free representation but the creation of foreseeable problems
- uses of spatial information for unintended purposes or in unintended ways.

In the first issue a court has considered the data entry process and considered whether or not a reasonable standard of care was exercised and whether procedures aimed at minimising errors had been used. In *Indian Towing Co. v. U.S.* [1955] 350 US 61 the Federal government was held to have negligently failed to have maintained a lighthouse marked on nautical chars. In *Remiga v. U.S.* [1978] 448 F.Supp. 45 the Federal government was held to have inaccurately and negligently depicted the location of a broadcasting tower on an aeronautical chart, contributing to mistakes that resulted in fatalities in an air crash. The second issue is illustrated by *Aetna Casualty v Jeppson & Co.* [1981] 642 F.2nd. 339 which concerned representations about error free data. Liability was found because the representation was held to be confusing and inappropriate for the intended purpose. The third issue is discussed in *Zinn v State* [1983] 112 Wis. 2nd 417. The case concerned evidence on the location of the ordinary high water mark (OHWM) for a navigable lake. This case illustrates both the use of a base map for a purpose unintended by professional cartographers and inappropriate combination of map features for land management purposes.

There are of course other legal issues that pose interesting conundrums that require further investigation. For example, if GIS is considered a product then it involves implied warranties for product liability. However, if a GIS is considered a service then it involves proof of negligence, a duty of care, proximate cause as well as errors and omissions. The distinction between products and services as intellectual property as distinct from 'records' is thus a critical legal issue. Contract law would also intrude if there was a contract so that third parties not privy to the contract may not obtain normal protection under the common law. The message is that there is a need for carefully constructed policy in order to avoid premature court challenges if geographic information is to have widespread use.

Conclusion

The ideas presented in this paper are only a first draft of possible scenarios. The questions that one might ask is whether one method of providing access is more efficacious than another and what some of the advantages are as against its drawbacks. The policy implications raised in this paper can be important in the long term not only in terms of the development of GIS as an everyday tool but also in terms of whether or not the technology will develop at all. The institutional setting is that we have an application of old rules to new technology and this opens the way to inappropriate literal applications of legal rules. Archer (1989: 1577) has noted that "the law does not change quickly by design and often fails to keep up with dramatic changes modern technology brings to our society".

An assumption of policy decision-making to intervene in an activity whether private, public or otherwise is predicated on the belief that the public interest is put at risk by the fulfilment of some private interest. The policy response may be in the form of education of the public, facilitation, regulation and providing incentives. Regulation requires the adoption of new behaviour whereas providing incentives are an attempt to induce new behavioural patterns. In the area of geographic information it seems that a combination of regulation and incentives may produce the desired effects in the production, use and future development of information products and services in the market-place.

Geographic information and its related vocabulary is continually being extended in ways which make it meaningful to speak in specific terms. The idea of information as a utility, just like any other utility suggests acceptance and widespread use of the technology. Logically, it follows that there surely will be an information infrastructure that will assist in the dissemination of this information. As well the data that are contained in these become part of the social infrastructure. However, it has been noted that "the legal and political liability of distributing geographical information is potentially the most explosive issue to accompany the introduction of geographic information technology" (Aronoff 1989: 284). The future of GIS, it has been noted is predicated upon government policies on information access, privacy rights and the role of the state (Rhind 1994). Unless we know what these are it will be impossible to chart the path ahead.

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TOWARDS A NATIONAL POLICY ON THE TRANSFER OF GEOGRAPHICALLY-REFERENCED DATA

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Introduction

The purpose of this presentation is to give an update on some significant developments in the area of information policy that will have a direct bearing on our ability to access geoscience information.

A number of recent Government inquiries and reports are mentioned, as key source documents. These are a backdrop to the current efforts of the ANZ Land Information Council, and in my local jurisdiction, the Commonwealth Spatial Data Committee, to bring together a national policy to clear impediments to geo-referenced data access.

More specific has been the government's recent funding of AGSO to set up a National Geoscience Information System. A recent client survey has shown good support for the concept.

Finally, mention is made of the future potential for enhanced access to relevant geoscience information required for GIS development, taking all of the above initiatives into account.

Government Information Policy Initiatives

Pressure for a Government information policy commenced in 1980s, championed by Dr Barry Jones (Dept Science, 1985 etc). A decade later, Jones was quoted that response to this need had been "lethargic, unsophisticated and fragmented" (Coleman, 1994). Several months later down the track leading to the "information superhighway", in 1995, things do not seem as bleak:

- there is a recognised need to upgrade Australia's technical and business infrastructure to support the information industries;
- telecommunications deregulation has commenced;
- government studies into expanding the research and public broadband networks were completed in 1994, 1995, and others are due;
- The foreshadowed Australian Land Related Data Transfer Policy will be a big step in a series of policies and standards affecting the *content* side of the equation;
- These developments will lead to a review of financial regulations and legal definitions relating to the status of information in society.

Some of the more significant sources/resources are mentioned in brief summary:

ASTEC report: Networked Nation (1994)

- Considered in some detail a technical report and submissions that looked at AARNet network capacity, growth, and considered the special needs of high bandwidth users.

- Proposed a consortium model for the development of AARNet, as well as greater involvement of government in information delivery using the Internet.

BSEG report: Networking Australia's Future (1994)

- The Broadband Services Expert Group proposed that a National Strategy for New Communications Networks be implemented based on three key elements: education and community access; industry development; and the role of government.

Clients First report (1995)

- This report, just released this month, is directed at making the government ready to take up the challenge of the future by ensuring it has "tuned its own use of information technology to the appropriate pitch and by developing strategies to take up opportunities to deliver better services while containing costs".

- It endorses the importance of government becoming a leading edge user of information technology to provide services, as highlighted in the BSEG report.

- The report states that "the Commonwealth because of its size, complexity and relevance to the lives of citizens, needs to develop a strategic view of how it participates in this new environment".

- There are 32 major recommendations, many with multiple parts, in this report. There is push to get major client service delivery agencies to provide a common information delivery mechanism regardless of administrative boundaries (Dept Finance, 1995).

A number of other significant sources supporting these studies, or relevant to our information policy focus are listed as an aid to further study:

- Building Australia's R&D Network (Culter & Company, 1994a);
- Commerce in Content (Culter & Company,1994b);
- Creative Nation (DoCA, 1994a) - funding for Australian CD-ROM *content;*
- Beyond the Duopoly (DoCA, 1994b) - telecommunications policy, post 1997;
- Communications Futures Project. Work-in-Progress Papers (BTCE, 1994);
- Computer Hardware Software & Related Service Industries (Ind. Commission, 1995)

Major reports or press releases on government information policy are also being listed or linked on the National Library server: <URL: http://www.nla.gov.au/lis/govnii.html>.

National Strategies for Information and Communications Services Technologies

I am taking Editor's liberty in adding highly relevant material at this point, following a major Prime Ministerial announcement a week after the GIS Forum. On 6 April 1995, in a series of press releases (Media Statements, 1995a,b,c,d,e), the Government announced it would "implement a national strategy aimed for the adoption of new information and communications services and technologies - the so-called "information superhighway":

a) Prime Minister Keating announced:

- the setting up of an **Ad Hoc Committee of Cabinet** to consider a national strategy, provide advice on broad national policy issues, and identify matters for discussion by government, industry and the community.

- He established the **National Information Services Council** under this peak body, as "a high level discussion forum for broad policy issues, providing industry and community input into the Government's consideration of the issues"; and

- He established a **Government Information Services Policy Board** (GISPB) to coordinate a user-driven whole-of-government approach to the Government's use of these important services and networks.

b) Minister Beasley announced that a **Chief Government Information Officer** (CGIO) would be appointed to promote standard solutions to common requirements, a "lead agency" concept, and a "strategic blueprint" for government use of information technology. The CGIO is to chair the GISPB, supported by an **Office of Government Information Technology**.

c) Senator Cook commissioned the Australian Science and Technology Council to undertake an assessment of the adequacy of Australia's science base to contribute to the development of information and communications services and technologies.

d) Minister Baldwin announced the first steps towards meeting the Government's commitment that all Australians would be able to access the benefits of electronic networks:

- A **Community Information Network (CIN)** will link a range of community facilities around Australia, including libraries and community organisations, into a public computer network;

- The CIN will provide access to information and communication facilities, such as e-mail and bulletin boards, to people who do not have a computer; and

- The CIN will provide free access to government and community information, communication facilities and services, via 300 library and community organisation access points.

e) Minister Crean announced the establishment of the **Australian Education Network** (or **EdNA** as it is now known) to "put education and training on the information superhighway":

- EdNA will link all schools, TAFEs and universities and other education and training providers across the nation;
- The network will also provide a publishing platform and a market for Australian education and information technology product;

- It will have "major advantages in ensuring affordable tariffs for network users"; and

- A directory of educational services and an interactive electronic message system will be accessed by students and teachers from education institutions and the home, regardless of location.

National Spatial Data Policy & Data Infrastructure:

I. Australia New Zealand Land Information Council

ANZLIC (Australia New Zealand Land Information Council) is the peak group for land and geographic information policy, and advises the Council of Australian Government (CoAG) Ministers. It has representation from each of the Australian States and Territories, and New Zealand. ANZLIC has been active in promoting and releasing booklets on geographic data policy issues, and held various workshops on data standards for resource and environmental data.

ANZLIC's vision is that: *"Australia and New Zealand will have the land and geographic data infrastructure needed to support their social, economic and environmental interests, backed by national standards, guidelines, and policies on community access to that data."*

ANZLIC's 1994-97 strategy for achieving this covers a range of actions in five key areas (ANZLIC, 1994):

- Data Infrastructure - describing the fundamental spatial data components needed
- Standards - eg promoting an Australian Spatial Data Transfer Standard
- Access to Information - identifying core metadata & national transfer policy
- Industry Development - eg cost/ benefit study (Price-Waterhouse, 1995)
- Organisational Framework - coordination models between jurisdictions.

Following the Agenda 21 Declaration from the 1992 United Nations Conference on Environment and Development, the Australian Intergovernmental Agreement on the Environment (IAE) was developed. ANZLIC was made responsible for key actions under Schedule 1 of the Agreement, including providing mechanisms to make land-related data more accessible across all levels of government and the private sector.

II. Draft National Policy for the Transfer of Land Related Data

- Coordinating committees in each jurisdiction considered drafts

- Workshops catered for input from groups not represented within jurisdictions, including Surveyor groups, Cartographers, GGDPAC

- A final version of the draft National Policy was agreed in Oct 1993 (ANZLIC, 1993)

- The National Policy is still at "draft" status, awaiting endorsement of the policy through their respective Cabinets.

- Some governments have not yet signed, although their agencies are acting in the spirit.

Purpose of the Policy

- to make data more accessible via a common approach to distribution and pricing;
- to avoid duplication and overlap in data collection, maintenance and maximise usage.

Principle

The Policy espouses the principle that:

> *"price should not be an impediment to transfer, and prices should be set at the lowest level which encourages efficient and effective use, avoids duplication and overlap in collection and maintenance of the data, and promotes data integration."*

Scope

The policy aims to apply to transfers of land-related data, from a custodian, within and between all levels of government and to the private sector. Land-related data is defined as:

> *"data about the land surface, aquatic marine and lower atmosphere, where the data can be related to geographic position"*

Affected Data Types - examples

- **Topography** - place names, heights, hydrography, bathymetry
- **Cadastre** - survey and parcel attributes (tenure, land use, value)
- **Resources and Environment** - soil, biota, water, climate, geophysical surveys, lithology, mineral & petroleum resource and tenure information
- **Socio-economic** - demographic, mining & agricultural statistics
- **Cultural** - heritage, aboriginal, restricted
- **Utilities** - power, water
- **Transport and Communications**
- **Administrative Boundaries** - statistical, electoral.

Custodianship

- Crucial to the effectiveness of the policy.

- Jurisdictions are required to designate agencies which have responsibility for particular data sets or classes of data.

- These responsibilities cover establishing standards for, and undertaking the collection, storage and maintenance of data.

- The custodian is thus the preferred source of the data, which avoids duplication.

- But the custodian is not necessarily the owner of, or holder of copyright for the data.

Directories

- Directories of datasets and their custodians are to be set up and maintained.

- ANZLIC supports the National Directory of Australian Resources (NDAR), maintained by the National Resource Information Centre (NRIC).

- Other directories may and do operate within jurisdictions, and should be uploadable to NDAR.

Charging for Data Exchange

1. Non-commercial Purposes

- Covers purposes which support environmental management, or government services for the public good (CSOs)
- Data for non-commercial purposes supplied at ***the cost of transfer***
- Cost of transfer covers costs actually incurred in transferring data
- Defined as including "... *computer processing costs, costs of consumables, distribution staff costs and associated overheads.*"
- The overheads may also include royalty payments.
- Custodians cannot seek to recover the costs of collecting, maintaining or upgrading data.

2. Special Processing

- Charges additional to cost-of-transfer allowed for supplying data in a form which the custodian does not maintain for its own purposes or for routine transfers
- This should apply pressure for the adoption of standards such as the Australian Spatial Data Transfer Standard (ASDTS)

3. Commercial purposes

- Including for reprocessing, on-selling, giving to another party or deriving revenue
- Jurisdictional policies on charging for goods and services apply.
- In some cases, these policies may allow commercial rights to be waived in the interest of facilitating public access to data.

Conditions of Use

- The custodian does not transfer copyright with the data
- Conditions of use are specified in a licence agreement, or memorandum of understanding.
- The policy does not override other issues such as privacy, confidentiality, liability, copyright, intellectual property, statutory obligations, national security, and international agreements.

III. Commonwealth Spatial Data Committee

- The coordinating body for spatial data issues in Federal government.
- One voting member on ANZLIC.

- The Committee is made up of senior representatives from the major relevant portfolios.

- Activities are currently carried out through its policy Coordination and Standards Sub-Committees.

IV. Draft Commonwealth Transfer Policy (CSDC, 1995a)

- Developed in parallel with the National policy on land-related data transfer.

- Goes further in attempting to widen access to public interest data.

- Acknowledges all sectors as potential data receivers - not just the public agencies.

- Proposal is that public interest data may be used for all purposes, including commercial.

- Policy to apply only to budget-funded agencies.

- Recommends that compliance in the case of specific GBEs be at the direction of the responsible Minister.

Commonwealth Charging Policy (draft)

- Needs to comply with existing Finance regulations on charging for goods and services.

- Exchange of products or services of comparable value is an acceptable alternative practice.

- Special arrangements are recognised, eg educational, research or international agreements.
- Charging is more carefully defined, as the ***average cost of transfer.***

- Earlier efforts to secure a policy position based on the marginal cost of transfer (direct supply costs) were not successful.

Average cost of transfer is defined as:

> *"The full costs of distribution incurred by the supplier in transferring existing data to another party are averaged over the estimated total number of units produced.*
>
> *The price of each product will include direct costs (for example media consumables, computer processing and freight) as well as an estimated pro-rata share of associated overhead costs in providing the distribution service (such as labour, operational, capital equipment, promotional, etc)."*

Supporting the Commonwealth Transfer Policy

- Requires developing policy guidelines and procedures.

- An issues paper has been developed so agencies can assess potential impact.

- Another paper explores in some detail the concepts of custodianship, lead agencies, and their rights and responsibilities (CSDC, 1995b).
- A model data licence has also been developed.
- Agencies are required to declare their public interest datasets and custodianship details in a schedule which is to be maintained by the CSDC.

National Scientific Information Network Initiatives

As a counterweight to the policy and pipe/delivery orientated initiatives for general information covered in the first few pages, it is worth noting recent national scientific information initiatives which are *content*, and also Internet oriented. These include:

- Environmental Resources Information Network - ERIN (1988 +)
  <URL: http://www.erin.gov.au>
- National Resource Information Centre - NRIC (1989+)
  <URL: http://yogi.nric.gov.au/nric/nricindex.html>
- Australian National Geoscience Information System - @ngis (1994+)
  <URL: http://www.agso.gov.au/information/>
- Australian Earth Observation Network - AEON (1996+?)
  Contact Stephen Wright, Space Office - initiative announced at the GIS Forum.

There are, of course, also a number of older national data collecting and distribution networks such as geophysical and meteorological, contributing to World Data Centres using conventional telecommunications networks and also the Internet.

Australian National Geoscience Information System - @ngis

The 1992 Review of the Australian Geological Survey Organisation (AGSO, ex Bureau of Mineral Resources) was aimed at improving the short and long term performance of Australia's geoscience effort. The Review, chaired by Dr Max Richards, issued its report the following May (Richards, 1993).

As part of its response to the Review, the government endorsed a recommendation for a new initiative aimed at enhancing access to geoscience information throughout Australia, and funding for a 3 year developmental program, commencing 1994/95. AGSO is responsible for managing the new NGIS Program, and is developing @ngis - the Australian National Geoscience Information System - as a primary delivery mechanism.

Although AGSO has the responsibility for coordinating the development of @ngis, much of the data and information relevant to @ngis is held by a range of organisations throughout Australia. The intention is not to duplicate existing holdings or to replace current access mechanisms. Rather the intention is to build linkages between people who can provide information and people seeking information so that both can benefit, using the Internet, World Wide Web model (Berman, 1994a,b).

@ngis Client Survey

To discover what potential geoscience data users and providers would want in such a system, AGSO commissioned a major client survey in November / December 1994 to assist in the planning of @ngis. The national (external) survey had three elements - a mailed questionnaire, a telephone survey and face-to-face interviews. This main survey covered a sample of some 2,000 people in the following five main sectors:

- Research (eg CSIRO, universities, R & D organisations)
- Exploration, Development and Associated Services (eg companies involved in minerals and petroleum exploration, and environmental geosciences, including those providing consultancy and contract support services)
- Government (eg geological surveys, departments, agencies)
- Community Interest (eg Landcare groups, environmental, Aboriginal and Torres Strait Islander interests, municipal libraries, schools)
- Non-Geoscience Industry/Business (eg legal and financial sectors, media, tourism, telecommunications, professional)

Survey Response and Findings

A good return of about 35% was obtained. Analysis consisted of quantitative and qualitative treatment of the tabulated mail questionnaire and telephone responses, and qualitative analysis of untabulated mail questionnaire and telephone responses and face-to-face interviews.

A comprehensive report on the survey findings was presented to AGSO, which contained much fine detail in the form of 24 tables cross-tabulating each question's category response sub-totals, against the various dimensions that had been constructed.

These dimension were:

- Type of organisation (the 5 client sectors);
- Size of business (1-7, 8-40, 41 or more people);
- Data usage (user, provider, both, neither); and
- Respondent's function (eg. researcher, manager, librarian, technologist, teacher...)

The survey findings are currently being reviewed, with the objective of holding follow-up workshops to provide feedback. The major areas where interesting results have been collated are in regard to:

- Awareness
- Understanding the Concept
- Desired Service Elements
- Data Usage/Provision
- Geoscience Interest
- Supporting Material of Interest
- Preferred Components of Geoscience Information System
- Suitable Hardware/Internet Connection
- Charging
- Interest in further participation.

It is intended to give a more detailed paper on the findings of this important survey at the Third National Conference on Geoscience Information and Data, to be held at the Australian Mineral Foundation, 17-21 July 1995.

Building @ngis

@ngis can be seen as an electronic gateway to geoscience data, or a "special interest network". A "web" of domains of geoscience and related information holdings can be envisaged, incorporating interested geoscience data gatherers, providers, and users from across government, industry, educational and other sectors.

Some strands of this web exist already, with a number of organisations providing data over the Internet and many users being part of the Internet community. The web will grow as more data providers and more users become part of it.

To improve access to this web it is envisaged that @ngis will provide an overarching query and access mechanism. For example, someone wanting to find data for a particular geographic area might query @ngis and be presented with a list of organisations and the data they have available. This person could then access the relevant organisation(s) electronically to obtain more information or to download permitted data, or alternatively approach custodians in person, by phone etc.. A more advanced system could dynamically join different distributed databases, returning a single map or list of data attributes. These could derive from existing, cooperating state-based systems.

Strategies for Developing @ngis

As a result of consultation through the survey, the following three strategic approaches have been reinforced:

1. Consult with data gatherers, custodians and users on the need to:

- identify user needs for data and related geoscientific information
- facilitate the development of linkages between existing data providers (whether gatherers or custodians)
- assist in increasing the availability of data in electronic form (including support for existing or new providers, and data capture)
- where necessary, design, develop and maintain appropriate databases to meet needs not presently satisfied
- improve means of finding what data exists and who holds it identify appropriate data access arrangements, including user interfaces, software tools, and charging regimes; and facilitate their adoption
- promote increased contact between providers and users.

2. Facilitate adoption of national geoscientific, including geo-cartographic, data standards

- support existing national (AMIRA, GGDPAC) and international initiatives
- develop and integrate authoritative attribute & symbols reference databases.

3. Promote the Internet and its associated software environment as key technologies for the delivery of @ngis

- set up a graphical, spatial, Internet-web based interface to data sources
- support sectoral and regional initiatives in the application of @ngis technology.

GIS and @ngis

AGSO's World Wide Web Internet server is currently a testbed for many of the @ngis technologies. An early objective is to enable direct access to appropriate Oracle geoscience databases (eg Stratigraphic Names) through a Forms interface running on a browser client software such as Mosaic or Netscape. This will involve the use of SQL*Net and some intermediate C conversion programs, but should be achievable this year.

More difficult will be the incorporation of GIS capability, involving the supply of themes or layers, and depending on raster backdrops or vector data types requiring special processing for current browsers. Research is underway in these areas in several overseas and Australian locations, and is being tracked. Developments in 3D and VRML capabilities of browsers will be as important as the necessity for common data models and entity/attribute definitions for SDTS transfer, as is being pursued through an AMIRA project (P431), supported by GGDPAC members.

In the mean time, the data cataloguing efforts that @ngis is able to stimulate, along with the generation of metadata, will be required as a first base - in order to locate relevant, quality datasets, and help further populate NRIC's NDAR system.

Sumary & Outlook

The policy framework which affects access to geoscience data - both technically and organisationally - has been outlined. The role of ANZLIC has been stressed, particularly as regards to its support for a national land-related data transfer policy. The Commonwealth's initiatives in this area have also been outlined, in particular the work of the CSDC, and the new @ngis initiative.

It is hoped that the new National Information Services Council can quickly expand its initial constituency to encompass data issues, perhaps through involvement with ANZLIC. All-round agreement to the national Transfer and Pricing policy might thereby be facilitated. In this forum, ANZLIC's (1995) Australian Land & Geographic Data Infrastructure Benefits Study might find ready acceptance. This would help state initiatives along the same lines such as that promoted by the Office of Geographic Data Co-ordination in Victoria (1993).

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SDTS (AS/NZS 4270) - where next with this Australasian Standard?

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Abstract: The Spatial Data Transfer Standard has been adopted by Standards Australia and Standards New Zealand as AS/NZS 4270.

Where next with this Australasian Standard? This paper discusses issues associated with the adoption of the standard by GIS users in Australasia. These issues include the introduction of profiles (subsets) of the standard, the current status of the development of dictionaries, and what software will be available. Another important related issue is what other geo-spatial transfer standards will be in use in Australasia and how these standards will coexist.

The paper also looks at the ease of creating an SDTS transfer. Major GIS systems are developing SDTS translators which will enable the easy export of SDTS transfers. This is illustrated with a discussion of how one exports a SDTS transfer through the GIS ArcInfo.

Where to from SDTS? The International Standards Organisation has established a committee, ISO/TC 211 - Geographic Information/Geomatics that will include the transfer of geographic information. This committee will need to integrate a number of international geo-spatial transfer standards which includes SDTS. Standards Australia is to play an important part in this committee.

INTRODUCTION

The Spatial Data Transfer Standard has now been adopted by Standards Australia and Standards New Zealand as AS/NZS 4270 and will begin to supersede other transfer standards and proprietary formats.

This paper is an update and revision of the information presented on SDTS at AURISA 94 (Hume and Miller, 1994).

In part answer to the question "Where next with this Australasian Standard?", this paper discusses issues associated with the adoption of the standard by GIS users in Australasia. These issues include the introduction of profiles (subsets) of the standard, the current status of the development of dictionaries, and what software will be available. Another important related issue is what other geo-spatial transfer standards will be in use in Australasia and how these standards will coexist.

The paper also looks at the ease of creating an SDTS transfer and this is relevant to how quickly SDTS will be accepted in Australasia. Major GIS systems are developing SDTS translators which will enable the easy export of SDTS transfers. This is illustrated with a discussion of how one exports a SDTS transfer through the GIS ArcInfo.

This standard has been strongly supported in Australasia by the Australia New Zealand Land Information Council (ANZLIC) and by the State land information councils and this too will be important to how readily SDTS will be accepted in Australasia.

Where to from SDTS? The International Standards Organisation has established a committee, ISO/TC 211 - Geographic Information/Geomatics that will include the transfer of geographic information. This committee will review a number of international geo-spatial transfer standards which includes SDTS. Standards Australia is playing an important part in this committee.

RATIFICATION OF SDTS

SDTS was developed in the US over some 10 years under the direction of the United States Geological Survey (USGS). It was signed by the Secretary of Commerce on July 29, 1992, as Federal Information Processing Standard, FIPS PUB 173, from the National Institute of Standards and Technology. The standard was gazetted in the US Federal Register on August 28, 1992. The effective implementation date for the standard was 6 months after that date on February 15, 1993. Use of FIPS PUB 173 became mandatory for US Federal Agencies one year after that date on February 15, 1994.

The Standards Australia Committee IT/4/2 (Geographic Data Exchange Formats) resolved to adopt SDTS to supersede the current Australian digital mapping exchange standard AS 2482.

Standards Australia requested revisions of the SDTS text from IT/4/2 members on August 3, 1992. This lead to the issue of a Draft Australian Standard for Comment, DR 93066, on April 1, 1993.

The final draft of the SDTS standard, modified for Australasian use, was distributed to the IT/4/2, for final comment in December 1993 and then to members of the Geographical Information Systems Committee, IT/4 for a postal vote which closed on May 27, 1994.

It was approved on behalf of the Council of Standards Australia on September 12, 1994 and on behalf of the Council of Standards New Zealand on September 28, 1994. It was published on January 5, 1995.

The standard now appears as the full US text with sideline bars highlighting all amendments and a separate appendix detailing each text revision. The changes are to include referencing systems for Australia and New Zealand, and equivalent Australian and New Zealand Standards and should have little impact on software developed for the US Standard.

THE AUSTRALIA/NEW ZEALAND STANDARD

SDTS have been issued in three parts by Australia/New Zealand:

Part 1.	Logical Specifications	AS/NZS 4270.1
Part 2.	Spatial Features	AS/NZS 4270.2
Part 3.	ISO 8211 Encoding	AS/NZS 4270.3

Standards Australia and Standards New Zealand have allocated a further number AS/NZS 4271 for dictionaries developed for the standard in these countries.

SDTS specifies a framework for the transfer of vector and raster spatial data which includes a conceptual model, data quality information, feature and attribute definitions and the physical encoding of the transfer. This framework covers a broad range of data types and SDTS will be used in a number of recognised subsets called profiles for each data type. The Topological Vector Profile and the Raster Profile are the first of these profiles to be specified.

PROFILES

SDTS profiles are specified to transfer a particular spatial data type like vector or raster data. The profiles detail the SDTS primitive spatial objects that are allowed in a transfer and details such as file naming conventions. Profiles must be ratified by a standards body as they specify an implementation of the standard that will be adopted by software suppliers. Australia/New Zealand are likely to adopt profiles that have been developed in the US at least for the medium term. The USGS has welcomed comments on profile specifications and on the SDTS standard itself and Australian comments have been adopted. The profiles in final and draft form are the Topological Vector Profile and the Raster Profile.

Topological Vector Profile (TVP)

The Topological Vector Profile (TVP) has been completed in the US and will be adopted by Standards Australia/Standards New Zealand. The changes to this profile are similar to those required for the Standard. This subset of SDTS is ideal for cartographic transfers. The profile is for two dimensional objects with topology. For example, each line must reference the areas to the left and right. The US National Institute of Standards and Technology (NIST) will publish a new version of the SDTS, FIPS 173-1, which includes the TVP as Part 4. The final version of the TVP (version 1.0) is dated June 10, 1994.

The US is developing "test points" for conformance testing of Topological Vector Profile transfers are being developed which specify what details must be present.

Raster Profile

The Raster Profile is important because of the availability of data in a raster format like satellite data and rasterised graphic information. The Raster Profile is near completion in the US and should be ready for public review there in mid May. The Raster Profile has lead to changes to SDTS which will also be available for review at that time.

DATA DICTIONARIES

SDTS has the facility to include the specification and definition of features and attributes with each transfer. However, it is preferable to have standard dictionaries of features and attributes that can be referenced by the transfer. Standard dictionaries lead to a common understanding of the features involved and also simplifies the transfer process. The Spatial Feature dictionary within SDTS is limited largely to the themes of topography and hydrography. Australia and New Zealand have chosen to extend the standard by developing a dictionary for each of a number of themes. This will lead to a faster implementation of dictionaries for themes in Australia but will require interaction between the teams developing the dictionaries to ensure the dictionaries are compatible.

The US is establishing a framework to extend the SDTS dictionary.

Current data dictionary developments in Australia/New Zealand are summarised below.

Topographic

The topographic data dictionary is being produced by the Intergovernmental Committee on Survey and Mapping (ICSM) as one of the tasks for that group in producing a National Digital Topographic Data Model. Mr Gary Isbel chairs the group developing the data dictionary. A draft containing entities and attributes will be issued for comment in three month to members of the dictionary development working party. The committee has adapted terms from sourced terms from SDTS (FIPS PUB 173, 1992), AS2482, the Land Use Coding Standard, ATSAS and DIGEST FACC.

Cadastral
A national working group under the ICSM was established to develop a cadastral data dictionary. Mr Peter Lores is convenor and Ron McLeod secretary of this group. The group released draft version 1 in March 1994, version 2 in November 1994 and will be releasing version 3, possibly the final version, in April 1995 for comment by the working group. The draft contains entities and attributes, their definitions and included terms. The domains were specified for some attributes.

Utilities
The Utilities dictionary was developed under Standards Australia Committee IT4/4/8. This dictionary will be issued for public comment in about a month.

Street Addressing
The street addressing standard was published on September 19, 1994 as AS 4212-1994 Geographic information systems - Data dictionary for transfer of street addressing information. This is an Australian Standard only and not a combined Australia/New Zealand Standard as with SDTS.

Geosciences
A Geoscience data dictionary will be developed under a project recently initiated through the Australian Mining Industries Research Association (AMIRA) and strongly supported by the Government Geologists Database Policy Advisory Committee. This project is funded by the Australian Geological Survey Organisation (AGSO), most State Geological Surveys and BHP and North companies. It aims to define a data model and data dictionary for selected Geoscience themes and is being project managed by AUSDEC. The project has a 3 year duration.

GIS VENDOR IMPLEMENTATIONS

SDTS has been mandatory in the US, for Federal Agencies, since February this year. Test data sets for SDTS are now becoming available from the USGS for digital cartographic data as with DLG-3, DLG-E and for census data as in TIGER formats and these can be obtained from Internet.

The development of translators for the standard by GIS software vendors is a crucial factor in the take up of this transfer standard. In the US, the mandatory requirement for US Federal Agencies to offer their data in the SDTS format will require GIS vendors to develop SDTS translators. SDTS in Australia does not have this mandatory requirement.

AUSDEC contacted the USGS for their comments on the progress of the major GIS vendors in the US in implementing SDTS. A summary of their comments is given below. The software being developed is for SDTS translators conforming to the Topological Vector Profile (TVP) subset of SDTS.

ARC/INFO (ESRI)
An SDTS/Topological Vector Profile (TVP) encoder and decoder will be a part of release 7.0 of ARC, which is due out sometime late in 1994. Included in release 7.0, will be commands that enable the operator to document his spatial data set (metadata).

By ESRI's own account these are primitive and are not fully functional translators. At this time the translators handle USGS DLG and Census Bureau TIGER data but have difficulty with other types of data. AUSDEC is trialing the translator currently for one of its consulting clients.

MGE (Intergraph)
Intergraph is currently working on an SDTS translator. It is expected it will become available during the 3rd Quarter of 1994. SDTS capability will be developed first for the MGE product on UNIX Workstations followed by MGE on Windows NT platforms. Intergraph is also working on software modules to implement metadata capability.

MapGraphix
MapGraphix is waiting for marketplace demand. Support for SDTS development will begin this year.

GDS (Graphic Data Systems Corporation)
GDS has an SDTS translator which first became available in November, 1993 using the Topological Vector Profile (TVP).

GENAMAP (GENASYS)
GENASYS is advertising that it has SDTS translator capability. Recent contacts with sales personnel indicate that the SDTS translator is currently not available, but it is under development as part of a project for the Milwaukee County Automated Mapping and Land Information System. In either case, GENASYS is actively pursing SDTS and translators are near completion if not already available.

ERDAS
ERDAS will support SDTS but a translator is not currently under development.

GRASS (USCERL)
SDTS translators are under development for GRASS. SDTS/TVP encoders and decoders will be available during the 3rd quarter of 1994. An SDTS Raster Profile translator is under development and is expected to be available in the 3rd quarter of 1994. GRASS is a public-domain GIS, as is this implementation for SDTS.

GEOLINK (Georesearch Corp.)
GEOLINK does not have an SDTS transfer module but is possibly looking into developing one.

SYSTEM 9 (UNISYS)
An SDTS/TVP translator is under development and near completion.

ARC/INFO SDTS TRANSFERS

We have gained some experience with producing an SDTS transfer using ArcInfo. Release 7 of this software has an SDTS translator for transfers to the TVP.

Transfers are relatively easy to generate. The steps in creating a transfer are:

separate node information from line and polygon information,
add topology to the line and polygon information,
define the projection information for the cover, and
issue the command to export this data in SDTS format.

The software writes each layer (cover) to a separate transfer. There are approximately 25 to 30 files per transfer.

Defaults can be changed through a separate conversion control file. In addition, this file is necessary to add data quality and dictionary information which are not included as defaults.

AUSTRALIAN DEFENCE FORCE INSTRUCTIONS

A number of other international geo-spatial transfer standards are being adopted in Australia. This is exemplified by the recently released Australian Defence Forces' Defence Instructions (General) OPS 20-3 which is titled "Digital Geographic Information Interchange Standards and Data Product Standards" dated May 6, 1994. "This instruction prescribes the standards which apply to digital geographic data exchange within Defence and digital geographic data products used by the Defence forces."

"Standards relevant to Defence for the exchange of digital geographic information are:

a. **Digital Geographic Information Exchange Standard (DIGEST)** for data exchange within Defence and with Australia's allies;
b. **Australian Spatial Data Transfer Standard (SDTS)** for exchange of data to, from and within the civilian community: and
c. **IHO Special Publication 57 Transfer Standard for Digital Hydrographic Data (S-57)** for exchange of digital hydrographic data for navigation."

The DIGEST standard was developed to facilitate the exchange of militarily significant geographic information and was sponsored by the Digital Geographic Working Group (DGIWYG), a group of North Atlantic nations. The standard has been adopted by NATO.

S-57 is an exchange standard sponsored by the Committee for the Exchange of Digital Data (CEDD) of the International Hydrographic Organisation (IHO) and was accepted by the IHO in 1992.

The International Maritime Organisation has incorporated S-57 in their Electronic Charts Display Information System (ECDIS). It is anticipated that within twelve months this standard will be ratified and will become international law.

While this specification is for the Australian Defence Forces it can be seen that these standards, SDTS, DIGEST and S-57, will all play a part in geo-spatial transfers in Australia.

ISO/TC 211 - GEOGRAPHIC INFORMATION/GEOMATICS

Where to from here with SDTS?

The International Standards Organisation has established a Technical Committee, ISO/TC 211 called Geographic Information/Geomatics. This committee will have a dominant influence on the development and use of standards for geographic information, in particular international geo-spatial transfer standards. One of the committee's tasks is to review the international defacto standards and establish whether they can be adapted into TC 211 standards.

The ISO committee has 5 working groups:

WG1 Reference Model

WG2 Geo-spatial data model
WG3 Geo-spatial data administration
WG4 Geo-spatial services
WG5 Functional standards

Standards Australia has moved to model its committee for this area, IT/4 - Geographical Information Systems along the lines of the ISO committee. Standards Australia is calling for experts to join these ISO working groups, particularly WG2 and WG5. Drew Clarke, who is currently chair of IT/4 is convenor of WG2. Australia will play an important role in the development or adoption of the future transfer standard.

REFERENCES

AS 4212:1994. Geographic information systems - Data Dictionary for transfer of street addressing information. Standards Australia.

AS/NZS 4270.1(2,3):1995. Geographic Information systems - Spatial data transfer standard. Standards Australia and Standards New Zealand.

FIPS PUB 173, 1992. SPATIAL DATA TRANSFER STANDARD (SDTS), Federal Information Processing Standards Publication. The US National Institute of Standards and Technology,

Hume, R.G. & Miller, D.R., 1994. Adoption of the Spatial Data Transfer Standard in Australia and New Zealand. AURISA 94. Sydney.

SDTS (AS/NZS 4270) - where next with this Australian Standard?

Dr Richard Hume
Don Miller

2nd National Forum on
GIS in the Geosciences

SUMMARY

- SDTS ratification
- Profiles
- SDTS and ANSI
- Dictionaries
- Vendor Implementation
- Example transfer
- ISO - the future

SDTS DEVELOPMENT

- Over 10 years development in the US

SDTS RATIFICATION IN THE US

- National Institute of Standards, FIPS PUB 173
  - Gazetted in US Federal Register
    - August 28, 1992
  - Implementation date
    - February 15, 1993
  - Mandatory for Federal Agencies
    - February 15, 1994

SDTS RATIFICATION IN AUSTRALIA/NEW ZEALAND

- Standards Australia/Standards New Zealand
  - Requested revision from IT/4/2 (Geographic Exchange Formats)
    - August 3, 1992
  - Draft Australian Standards for Comment, DR 93066
    - April 1, 1993
  - Final draft for comment to IT/4/2
    - December, 1993

SDTS RATIFICATION IN AUSTRALIA/NEW ZEALAND (cont.)

- Postal vote IT/4 (Geographical Information Systems)
  - May 27, 1994
- Approved on behalf of Council of Standards Australia
  - September 12, 1994
- Approved on Behalf of Council of Standards New Zealand
  - September 28,1994
- Published
  - January 5, 1995

SDTS ISSUED IN THREE PARTS

Part 1.	Logical Specifications	AS/NZS 4270.1
Part 2.	Spatial Features	AS/NZS 4270.2
Part 3.	ISO 8211 Encoding	AS/NZS 4270.3

PROFILES OF SDTS IN US

- Topological Vector Profile (TVP)
  - Final Version June 10, 1994
- Raster profile
  - public review in mid May, 1995

SDTS AS AN ANSI STANDARD

- SDTS currently a project under ANSI X3L1
- 5 parts - 3 parts plus 2 profiles
- public comment period probably in July
- SDTS then maintained by ANSI

GIS VENDOR IMPLEMENTATION

- ARC/INFO (ESRI)
- MGE (Intergraph)
- MapGraphix
- GDS (Graphic Data Systems Corporation)
- GENAMAP (GENASYS)
- ERDAS
- GRASS (USCERL)
- GEOLINK (Georesearch Corporation)
- SYSTEM 9 (UNISYS)

DATA DICTIONARIES

- Topographic
- Cadastral
- Utilities
- Street Addressing
- Geosciences

ARC/INFO SDTS TRANSFERS

- Translator in Release 7
- Translation to TVP (latest release)
- Translator easy to use

ARC/INFO TRANSLATION STEPS

- Separate node from line information
- Add topology to line information
- Define the projection information
- Issue the command to export

ARC/INFO - NOTES ON THE TRANSLATION

- Each layer (cover) in a separate transfer
- Defaults changed through a conversion_control_file

AUSTRALIAN DEFENCE FORCE INSTRUCTIONS

- Digital Geographic Information Exchange Standard
  - (DIGEST)
- Australian Spatial Data Transfer Standard
  - (SDTS)
- IHO Special Publication 57 Transfer Standard for Digital Hydrographic Data
  - (S-57)

ISO/TC 211 - GEOGRAPHIC INFORMATION/GEOMATICS

- WG1 Reference Model
- WG2 Geo-spatial data model
- WG3 Geo-spatial data administration
- WG4 Geo-spatial services
- WG5 Functional standards

THE AUSTRALIAN STANDARD DATA MODEL FOR THE GEOSCIENCES

R.G. Hume, Senior Consultant and D.R. Miller, Executive Director
Australasian Spatial Data Exchange Centre

Abstract: An Australian Standard data model is being developed for the geosciences. The data model, called the Geoscience Data Model, will provide a definition of geoscience data and the relationships between this data. This data model will provide a common basis of understanding for geoscience data through a common language and a common structure for geoscience information.

The requirement for a standard geoscience data model has been recognised in Australia for some time. A working group of the Australian Government Geologists Database Policy Advisory Committee began investigating geoscience data models in 1991. This led to their strong support for the Geoscience Data Model project.

The project is a joint government and industry funded project and is managed through the Australian Mineral Industries Research Association, AMIRA.

The Geoscience Data Model will be particularly important to both government agencies and the mineral industry as each are developing increasingly complex databases of geoscience information.

INTRODUCTION

An Australian Standard data model is being developed for the geosciences. The data model, called the Geoscience Data Model, will provide a definition of geoscience data and the relationships between this data. This data model will provide a common basis of understanding for geoscience data through a common language and a common structure for geoscience information.

The requirement for a standard geoscience data model has been recognised in Australia for some time. The Australian Mineral Industries Research Association, AMIRA, gained support for this geoscience data modelling project from the Geological Survey Organisations and Industry with strong support from the Government Geologists Database Policy Advisory Committee.

AMIRA is a not-for-profit research broker established by and working for the Australian Mining and Petroleum Industry.

The Geoscience Data Model will be particularly important to both government agencies and the mineral industry as each are developing complex databases of geoscience information.

BACKGROUND

International organisations are developing data models for their industries. POSC, the Petrotechnical Open Software Corporation has developed a data model for petroleum industry technical data as a key project in defining an integrated environment. A European Community project called DEEP, Database for the Exploitation of Exploration and mining Project, is looking at the structure of data.

The need for geoscience data models has been recognised, too, for some time in Australia. The Government Database Policy Advisory Committee, GGDPAC, established a Geoscience Data Standards Working Group in October 1991 which drafted a comprehensive list of data categories for geoscience.

Limited data model development, for the mining industry, was being done at that time as part of a project called AMDEX. This was an AMIRA project to specify a transfer standard for the mining industry data. AMDEX uses the Spatial Data Transfer Standard (SDTS)[1] and each SDTS transfer requires a data dictionary of terms to be either available as a standard or carried within the transfer itself. The transfer also requires a schema of the data to be transferred. Geoff Wood of AGSO saw the need to extend these data models beyond the immediate AMDEX requirement and with the strong support of GGDPAC through David Berman this lead to the project being initiated.

An AMIRA project planning meeting was held with potential Sponsors on 15 November, 1993. Sponsors were sought for the project and it commenced on 1 July, 1994.

The first Sponsors' project meeting for the Geoscience Data Model was held on Monday, 10 October, 1994, to select the most important geoscience themes for the Sponsors, to gain acceptance for the process of developing the data models and to establish the teams to develop the data models for the themes selected.

PROJECT SPONSORS

The Organisations that sponsor the Geoscience Data Model project through AMIRA are:

Australian Geological Survey Organisation,
BHP Minerals, Exploration,
Department of Energy and Minerals, VIC,
Department of Minerals and Energy, QLD,
Department of Minerals and Energy, WA,
Department of Mineral Resources, NSW,
Department of Mines and Energy, NT,
Department of Mines and Energy, SA, and
North Exploration.

The Sponsors are from almost all the Geological Survey Organisations in Australia together with two major Industry representatives. There is a continued effort to increase sponsorship from Industry to achieve a balance in the development direction for the project. This is important because of the interaction between Government Agencies and Industry.

THE PURPOSE OF A DATA MODEL

The Geoscience Data Model will be used in a number of ways. Some of these are:

providing a common basis of understanding of geoscience data,
describing data to be collected,
used in the development of computer systems for geoscience,
defining data bases, and
defining data transfers.

The data model will provide a reference in specifying data required by Government Agencies and by Industry for both written and digital information and this will provide a common understanding of the data.

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1 SDTS has been ratified by Standards Australia and Standards New Zealand as AS/NZS 4270:1995. The ability of SDTS to accept a data model (a dictionary of terms plus a schema) of the data to be transferred gives it flexibility.

The data model will be an important open systems component for developing computer systems and in defining data bases. Open Systems enables computer systems to work together enabling more flexible, easy to use and more powerful systems for the future.

As mentioned for SDTS, many of the international data transfer standards require a data model to define the transfers.

THEMES

The Geoscience Data Model has been funded for 3 years and this funding for the first year allows for four themes to be initiated.

The sponsors have assigned the following geoscience themes as their first priority:

geological data
geochemical data,
drilling data, and
mineral resource/reserve data.

It was recognised that the Sponsors had considerable expertise in developing geoscience data models in these areas in their role as data custodians and that the project could be more rapidly progressed for some themes by making use of these data models. Consequently, the first stage of the project was to collect and to review the data model/data dictionary documentation of the Sponsors for the four themes.

THEME DEVELOPMENT BY TEAMS

A project team has been established to facilitate and coordinate the operation of teams for each geoscience theme. The project team will be responsible for setting the methodology used to develop the data models. The team consists of a Project Manager, Don Miller, a Geoscience Coordinator, John Parker, and a data Modeller, Richard Hume.

The Geoscience Coordinator will be responsible for drawing together a Board of Experts for the development of the data models. Each Expert will be well recognised and accepted in the discipline required. The Coordinator will assist in the formation of a team under each expert.

Each team will be selected by an expert to work to a geoscience theme.

DATA MODEL PRESENTATION

The data model will be defined in geoscience features (entities) and the characteristics of these features (attributes). Efforts will be made to select features that are physical things like roads, bore holes, samples and haul roads rather than table names for collections of attributes.

The data model will be recorded as:
a dictionary of the entities and attributes
entity relationship diagrams of the data models, and
attributes for the entities.

The data model will be recorded using a data modelling tool (CASE tool) called System Architect by Popkin Software and Systems Incorporated. The data modelling tool will be used to record and present the data models and will allow consistency checks to be made on the data model.

The Geocentric Datum of Australia - A Co-ordinate System for the 21st Century

Jim Steed
Australian Surveying and Land Information Group (AUSLIG)

Introduction

In November 1994 the Intergovernmental Committee on Surveying and Mapping (ICSM) adopted a new coordinate system for Australia, to be implemented by the year 2000. This new system is known as the Geocentric Datum of Australia (GDA) and is compatible with the Global positioning System (GPS).

The decision to adopt this new system was the culmination of many years of discussion and preparatory work, and was a response to growing demand by major users of GPS technology. The International Civil Aviation Organisation (ICAO), the International Hydrographic Organisation (IHO), the International Association of Geodesy (IAG) and the International Federation of Surveyors (FIG) have all recommended the adoption of a geocentric coordinate system. The UN Regional Cartographic Conference for the Asia-Pacific region has also passed a resolution for calling all countries in the region to use a geocentric datum for surveying and mapping. These decisions have flowed on to the equivalent Australian organisations, and many other organisations are following a similar path.

Although those with professional expertise can competently use either local or global coordinate systems, the vast majority of future GPS users will not be familiar with coordinate systems; they will be users of cars, boats, planes and digital products, and cannot be expected to have, an understanding of coordinates and datums. It is therefore important that the coordinate system used for Australian products, is compatible with the global technology.

What is a Datum?

A point on the earth's surface may have a number of different coordinate values, depending on which datum is used. The datum is a combination of the coordinate reference frame, the particular geometric shape used to represent the earth (the ellipsoid) and one or more origin sites used to locate and orient this ellipsoid to the reference frame. An ellipsoid on its own does not therefore define a datum; the same ellipsoid could be used with different reference frames to produce different datums.

A reference frame usually has its origin at the centre of mass of the earth, as defined by Satellite Laser Ranging (SLR), and is defined by "the Cartesian coordinates and velocities adopted for various primary observing stations of the International Earth Rotation Service" (IERS) (Nautical Almanac Office, 1992). As more observations are obtained and computational techniques improve, revised reference frames are produced, generally on an annual basis, and are known as the IERS Terrestrial Reference Frame (e.g. ITRF92). This process is now refined to the stage where the difference between reference frame updates is at the centimetre level.

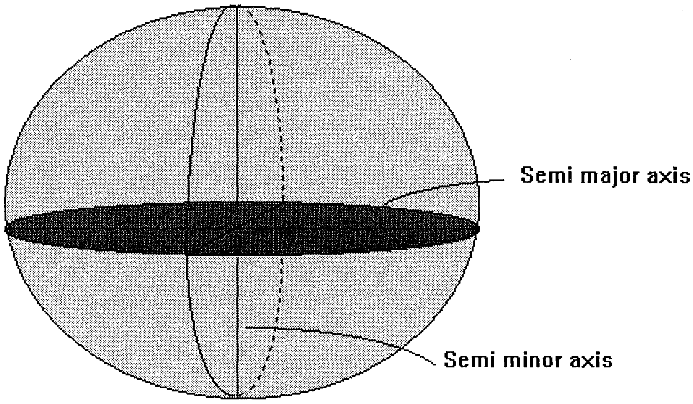

Figure 1 - Ellipsoid

An ellipsoid is a geometric figure, formed by rotating an ellipse, which is used to approximate the shape of the earth. It is also sometimes referred to as a spheroid, and is defined by its semi-major (a) and semi-minor axis (b). The flattening (f) is the relationship between these two axes (f = 1-b/a).

Ideally the ellipsoid should be centred on the earth's centre of mass, in which case the datum is known generically as an earth-centred (geocentric) datum. However in the past this was not always possible and datums were established to be a best fit to a particular region.

Coordinates in Australia

Clarke 1858

Prior to 1966 there were some twenty different datums using four different ellipsoids. The ellipsoid used for most national mapping coverage was the Clarke 1858 ellipsoid and coordinates of this type were conveniently referred to as 'Clarke' coordinates. In fact there were a number of different datums because of the different astronomically determined origin points used and the difference in coordinate value caused by these different origins could be as much as 300 metres. Although superseded for almost 30 years these coordinates continue to appear.

Australian Geodetic Datum

In April 1965, after much preliminary investigation, a best fitting local spheroid was adopted for the Australian region and was known as the Australian National Spheroid (ANS):

Semi-major axis(a) = 6 378 160 metres

Flattening (f) = 1/298.25

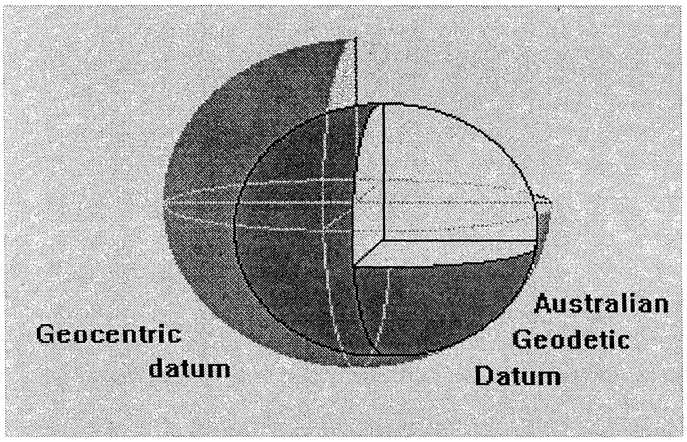

Figure 2 - Australian Geodetic Datum

In May 1965, a complete recomputation of the geodetic surveys of Australia was begun. A central origin was defined in terms of the Johnston memorial cairn; the ANS was oriented by defining the minor axis to be parallel to the earth's mean axis of rotation at the start of 1962 and defining the origin of geodetic longitude to be 149 00'18.855" west of the vertical through the photo zenith tube at Mt.Stromlo observatory. "The size, shape, position and orientation of the spheroid were thus completely defined, and together defined the Australian Geodetic Datum (AGD)." (Bomford, 1967).

On 6 October 1966 the Australian Geodetic Datum was proclaimed in the Australian Commonwealth Gazette. The adoption of this origin and best fitting local ellipsoid meant that the centre of the ANS was about 200 metres from the centre of the earth's mass.

AGD66

The recomputation of the geodetic surveys of Australia culminated in March 1966, with a least squares adjustment of the Australian geodetic network, using the gazetted Australian Geodetic Datum. This adjustment produced a set of coordinates which, in the form of latitudes and longitudes, is known as the Australian Geodetic Datum 1966 coordinate set (AGD66). The grid coordinates derived from a Universal Transverse Mercator projection of the AGD66 coordinates, using the Australian National Spheroid, are now known as Australian Map Grid 1966 coordinates (AMG66).

AGD84

In 1982 a new national adjustment, was performed using all the data previously included in the 1966 adjustment as well as additional, modern observations. This new adjustment also used the gazetted Australian Geodetic Datum (Allman & Veenstra, 1984). The coordinate set resulting from this adjustment was accepted by the National Mapping Council in 1984 and are known as Australian Geodetic Datum 1984 coordinates(AGD84). The Universal Transverse Mercator grid coordinates, projected using the Australian National Spheroid, are known as Australian Map Grid 1984 coordinates (AMG84).

WGS84

From time to time a geocentric coordinate system which is a best fit for the whole earth is produced, based on the latest information. One such system, the World Geodetic System 1972 (WGS72) was used for the Transit satellite navigation system, and also initially for the GPS system. The Geodetic Reference System 1980 (GRS80) was used by the United States Defense Mapping Agency as the basis for the World Geodetic System 1984 (WGS84), which is currently used for the GPS satellite navigation system (Kumar, 1988).

Geocentric Datum of Australia

When the AGD84 coordinate set was adopted by the National Mapping Council in October 1984, it recognised the need for Australia to eventually adopt a geocentric datum. In 1987, ICSM (the successor of the National Mapping Council) also saw the need for Australia to move to a geocentric datum compatible with satellite positioning systems such as GPS. It was particularly concerned with the diverging use of coordinates across Australia (AGD66, AGD84, WGS72, WGS84) and recommended a geocentric datum by the year 2000. However it was agreed that members could use their discretion in the timing of this conversion process.

The Australian Fiducial Network

The Australian Fiducial Network (AFN) is a network of eight geologically stable marks with permanent GPS tracking. There are several reasons for this network: (1) To provide continuous monitoring for crustal dynamics; (2) To provide continuous monitoring for GPS integrity; (3) to provide a means of legal tracability for GPS measurement and positioning; and (4) to provide the framework for the new Geocentric Datum of Australia.

To provide wider coverage for the first two of these aims, additional sites have been located at Cocos Island, Macquarie Island, Wellington (New Zealand) and Casey, Davis and Mawson in Antarctica. These sites together with the AFN comprise what is known as the Australian Regional GPS Network (ARGN).

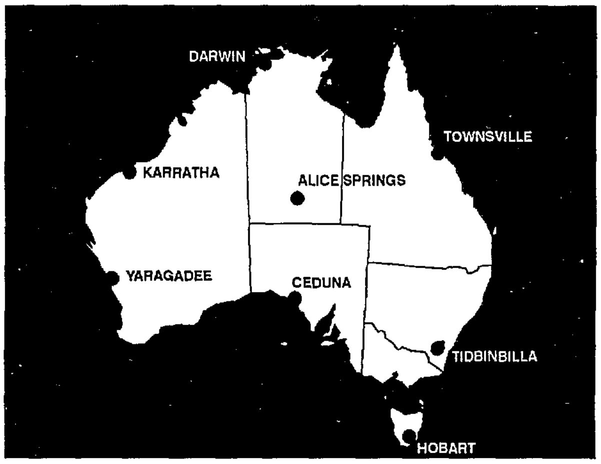

Figure 3 - The Australian Fiducial Network

The AFN sites were part of an global GPS observation campaign in 1992. This campaign included about two hundred sites throughout the world which observed during the two week period from 25 July to 8 August 1992. Many of these observations were included in a global solution which provided the geocentric positions for the AFN sites, with an estimated accuracy of better than 0.1 parts per million. These positions form part of the definition of the Geocentric Datum of Australia, together with the IERS Terrestrial Reference Frame for 1992 (ITRF92) at an epoch of 1994.0. To express these positions as latitudes and longitudes the Geodetic Reference System 1980 (GRS80) ellipsoid is used, and the resulting set of latitudes and longitudes are known as GDA94 coordinates. The Universal Transverse Mercator projection of these coordinates, is known as the Map Grid of Australia 1994 (MGA94).

It should be that although the GDA94 adjustment resulted in ellipsoidal heights for the AFN sites, the datum for heights in Australia has not changed and will remain as defined in the 1971 - the Australian Height Datum (AHD).

The Australian National Network

THE AFN has been densified with an additional seventy eight existing survey marks at approximately 500 km intervals across Australia. These sites, known as the Australian National Network (ANN), were observed with GPS as part of an ICSM cooperative project during 1993, with some additional observations in 1992 and 1994. This network of sites was included with the AFN during the global GPS adjustment and forms the framework for the GDA.

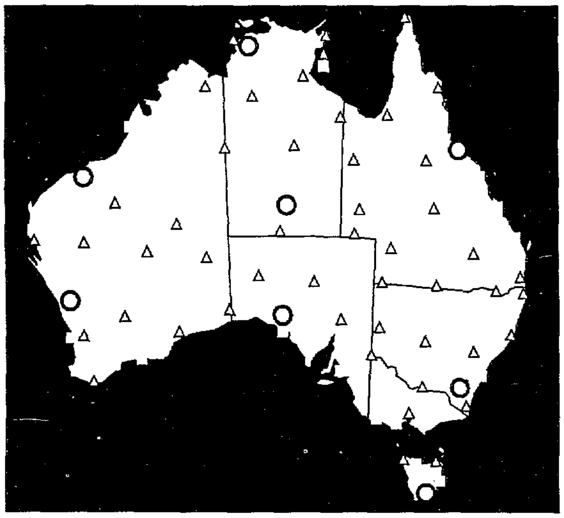

Figure 4 - The Australian National Network

Some States are very keen to implement the GDA94, while others will introduce it between now and the year 2000. As part of this implementation a number of states already have in place a supplementary network of GPS stations at about 100 km intervals. During 1995, these networks, together with the existing conventional survey networks used in the AGD84 adjustment, are to be combined in an adjustment constrained to the AFN and ANN sites. This will provide an additional five thousand GDA coordinates.

Differences Between Coordinates

AGD66 and AGD84 both use the gazetted Australian Geodetic Datum and the coordinates differ only because of the readjustment using additional data and improved adjustment techniques. The difference between these two coordinate sets varies from about 2 metres in south east Australia, to about 5 metres in the north west, but the variation is not uniform. Because of the non-uniform nature of AGD66 there are no national transformation parameters available to automatically transform between AGD66 and AGD84, though it may be possible to compute parameters for small regions.

WGS84 is earth-centred while the AGD is offset from the earth's centre of mass. This results in both AGD84 and AGD66 positions differing from WGS84 positions by about 200 metres. National transformation parameters are available to transform between AGD84 and WGS84.

The ITRF92 on which GDA94 is based, and the WGS84 system which is used for GPS are both earth-centred, but ITRF92, being a later model, is an improvement over WGS84. One of the requirements in the definition of GDA was that it should be within one metre absolute of WGS84. Initial tests showed that this criteria was met, but in addition, the WGS84 system was slightly modified at the beginning of 1994 and is now in even closer agreement with the ITRF. The production of ITRF updates is now refined to the stage where the difference between subsequent models is at the centimetre level, and will only be relevant for highly accurate scientific projects.

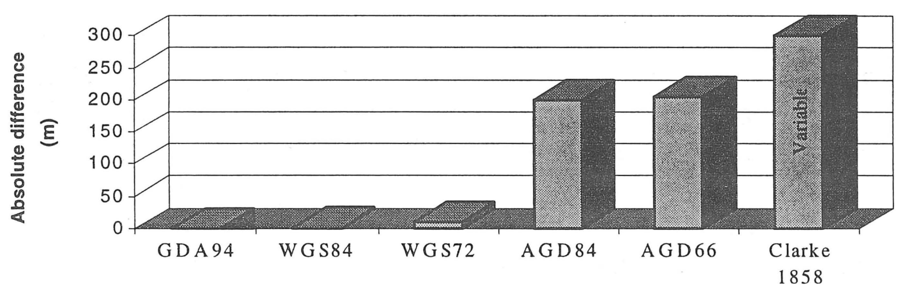

Figure 5 - Nominal differences between coordinates

Converting to GDA

The timing of the conversion to GDA94 will probably be influenced by user demand and the timing of related authorities. The conversion has been completed at the national level, is in hand at the State level, and will gradually flow on to other users.

To convert to GDA94 you must firstly know what coordinates system has been used for your existing data. You may then immediately convert all your data to GDA94, or convert on demand. Conversion of all data produces a consistent data set, but conversion on demand may minimises the amount of data to be converted. In any case, new data should be collected in terms of GDA94 whenever practicable.

Data sets may be converted to GDA94 by re-observation, re-calculation or transformation. If the existing data is of dubious quality, the opportunity may be taken to re-collect it, this time in terms of the GDA94 system. If the original observations are still available, it may be possible to reprocess them using the GDA94 specifications. Generally though, the most efficient method of converting positions to GDA94 is to mathematically transform them.

If a number of points have coordinates in terms of both the existing system and GDA94 (‘common’ points), they can be used to determine the GDA94 coordinates of other sites. The method of transformation depends the accuracy requirements and the number and distribution of these ‘common points’.

Block Shift

A simple method of transforming between two different coordinate systems is to directly apply the change in position determined from the common points. This block shift may be in terms of: geographical coordinates (latitude, longitude), grid coordinates (easting, northing), or earth-centred Cartesian coordinates (X Y Z). An average block shift may be inaccurate if the range of block shifts over the area is too large, in which case the block shift may be interpolated by graphical means (contours of shifts plotted from differences at common sites), or by a mathematical process (e.g. least squares surface fit, or Conformal transformation). The accuracy of this transformation method is entirely dependant on the accuracy of the common point coordinates and the interpolation method used. It generally involves some manual intervention and is best suited to small areas, although it can be used over larger areas if a lower level of accuracy is acceptable.

Molodensky's Formulae

The United States Defence Mapping Agency developed a simplified transformation method which uses an average origin shift (at the centre of the earth) and the change in the parameters of the two ellipsoids used. Transformation parameters are available to convert from either AGD66 or AGD84 to WGS84, but they "may produce results that are of insufficient accuracy." (DMA, 1987).

As WGS84 and GDA94 are the same to better than a metre, and limited tests have shown that Molodensky's conversion from AGD84 to WGS84 has an accuracy of about 5 metres horizontally and 10-15 metres vertically, they could be used as a conversion to GDA94 for lower quality data sets. New GDA94 parameters for use with Molodensky's formulae will be available late in 1995, but they are still expected to have an accuracy of no better than a couple of metres.

Similarity Transformation

Provided the rotation angles are small (a few seconds), the relationship between two consistent, three dimensional coordinate systems can be completely defined by seven transformation parameters: three origin shifts, three rotations and a scale change in parts per million (Harvey, 1986).

Once the parameters are available, the transformation is a relatively simple mathematical process, but because this technique is in terms of earth-centred Cartesian coordinates (X Y Z), the points to be transformed must be converted to this type. This means that ellipsoidal heights are used on input and are produced on output, but a large error in ellipsoidal height (hundreds of metres) has negligible effect on the transformed horizontal position (millimetres). The conversion between latitude, longitude and ellipsoidal height and earth-centred Cartesian coordinates is a relatively simple operation which can be included in the transformation process.

The accuracy of this transformation method is dependant on the accuracy of the seven parameters, which are derived from common points by least squares estimation. Existing parameters used to transform between AGD84 and WGS84 have an accuracy of a few metres, and can be used as preliminary parameters to transform between AGD84 and GDA94 (Higgins, 1987). provisional parameters to convert between AGD84 and GDA94 have already been developed and indicate an accuracy of less than a metre. These parameters are expected to be finalised later in 1995.

Summary

A number of different coordinate systems have been used in Australia. To ensure Australia's spatial data sets are nationally and globally compatible, a geocentric coordinate system known as GDA94 has been adopted and will be implemented up to the year 2000. Techniques to convert existing coordinates to GDA94 are available and will be supplemented in the near future by updated transformation parameters, which will be freely available through AUSLIG's electronic Information Service:

Internet access via the World Wide Web:
http://www.auslig.gov.au/welcome.htm: or
Internet access via gopher:
gopher.auslig.gov.au: or
Modem access to the computer Bulletin Board (BBS):
06-2014375 or 06-2014378

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Annex A

GDA Technical Specifications

Datum	Geocentric Datum of Australia (GDA)
Geographical coordinate set (latitude and longitude)	Geocentric Datum of Australia 1994 (GDA94)
Grid coordinates (Universal Transverse Mercator)	Map Grid of Australia 1994 (MGA94)

Terminology

Reference Frame	ITRF92 (IERS Terrestrial Reference Frame 1992)(1)
Epoch	1994.0
Ellipsoid	GRS80(2)
Semi-major axis (a)	6,378,137.0 metres
Inverse flattening (1/f)	298.257222101

Definition

Notes
(1) ITRF92 is recommended by the International Association of Geodesy and for all practical purposes is equivalent to the WGS84 system used by GPS.

(2) The GRS80 ellipsoid is effectively identical to WGS84 ellipsoid.

Annex B

Abridged Molodensky Formulae

Conversion from AGD to WGS84

Parameters

From	AGD66	AGD84
A	6378160 m	6378160 m
1/F	298.25	298.25
DX	-133	-134
DY	-48	-48
DZ	148	149
DA	-23	-23
DF	-0.000000081204	-0.000000081204
Sin1″	0.00000484814	

Definitions

DLAT	correction to local latitude to give WGS84 latitude (secs)
DLON	correction to local longitude to give WGS84 longitude (secs)
DHT	correction to local ellipsoidal height to give geocentric ellipsoidal height (m)
DX	origin shift along the X axis (m)
DY	origin shift along the Y axis (m)
DZ	origin shift along the Z axis (m)
A	Local ellipsoid semi-major axis (m)
F	Local ellipsoid flattening
DA	Change in ellipsoid semi-major axis (local to geocentric) (m)
DF	Change in ellipsoid flattening (local to geocentric) N Value
N Value	The separation, along the plumb line, between the ellipsoid and the geoid.
E2	Local ellipsoid first eccentricity
RN	Radius of curvature in the prime vertical (m)
RM	Radius of curvature in the meridian (m)
LAT	Local latitude (south negative)
LON	Local longitude (east positive)

Formulae:

$$E2 = 2F - F^2$$
$$RN = A / (1 - E2*SIN^2(LAT))^{0.5}$$
$$RM = A(1 - E2) / (1 - E2*SIN^2(LAT))^{3/2}$$

$$DLAT = (-DX*SIN(LAT)*COS(LON) - DY*SIN(LAT)*SIN(LON) + DZ*COS(LAT) + (A*DF + F*DA)*SIN(2*LAT))/(RM*Sin1'')$$

$$DLON = (-DX*SIN(LON) + DY*COS(LON))/(RN*COS(LAT)*Sin1'')$$

$$DHT = DX*COS(LAT)*COS(LON) + DY*COS(LAT)*SIN(LON) + DZ*SIN(LAT) + (A*DF + F*DA)*(SIN^2(LAT)) - DA$$

```
LATITUDE (geocentric)         = LATITUDE(AGD) + DLAT
LONGITUDE (geocentric)        = LONGITUDE(AGD) + DLON

ELLIPSOIDAL HT(local)         = MSL HT + N VALUE(Local)
ELLIPSOIDAL HT (geocentric)   = ELLIPSOIDAL HEIGHT (Local) + DHT
```

Annex C

Similarity Transformation
Conversion from AGD84 to WGS84

Parameters

DX	-116.00 m
DY	-50.47 m
DZ	141.69 m
R_x	-0.23 sec
R_y	-0.39 sec
R_z	-0.344 sec
Sc	0.0983 ppm

Formulae

$$\begin{vmatrix} x' \\ y' \\ z' \end{vmatrix} = \begin{vmatrix} DX \\ DY \\ DZ \end{vmatrix} + (1 + Sc*10^{-6}) \begin{vmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{vmatrix} \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}$$

Where :

X Y Z	is the geocentric Cartesian position of the point to be transformed,
DX	is the change of origin along the X axis in metres,
DY	is the change of origin along the Y axis in metres,
DZ	is the change of origin along the Z axis in metres,
R_x	is the rotation about the X axis in radians,
R_y	is the rotation about the Y axis in radians,
R_z	is the rotation about the Z axis in radians,
Sc	is the change in scale in parts per million (ppm).
x' y' z'	is the geocentric Cartesian position of the transformed point.

Scientific Dataset Catalogues

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Introduction

The impact of the information explosion is no more evident than in organisations dealing with scientific datasets. These organisations typically acquire very large datasets with great rapidity. The need to rapidly locate and access these datasets is also increasing with a more integrated approach to their usage in an ever decreasing time frame. These changes appear to be occurring at exponentially increasing rates and are leading to an information management crisis.

One approach to information management is to develop dataset catalogues (or directories) which assist the user to readily locate and access the required datasets. Several Australian organisations have developed such systems with varying levels of success. The current level of awareness for the need for such systems has been assisted by these developments and there is now considerable experience to be drawn upon.

Our own experience, in developing and utilising scientific dataset catalogues, has shown that there are a number of key factors which organisations must take into account if they are to build and maintain a successful dataset catalogue.

In this paper, we have restricted ourselves to discussions about catalogues for scientific datasets as this is our area of experience. Many of the issues we raise are about people and organisations and these probably relate equally well to non-scientific datasets. The dataset description and usage issues, however, may not be generally applicable.

Terminology

Our understanding of a dataset catalogue (or directory) is that it is a system which describes each dataset and points the user to its location. A key aim of these systems is to enable users to determine the relevance and quality of a dataset for a specific purpose without requiring the dataset itself to be acquired and examined.

The description of each dataset is its metadata (or "data about data") and includes information about the content, accuracy and purpose of the dataset as well as how and who it can be acquired from. The term 'metadata' appears now to be well understood (although to a computer scientist it might mean a low-level description say of the format of a file).

The term 'metadata' has lead to the use of the term 'metadatabase' for the collection of dataset descriptions. We do not believe that the term 'metadatabase' is appropriate as it can have the sense of 'a very large database.' We prefer to use the term catalogue rather than the term directory as the latter has the implication of a simple list of items rather than a comprehensive description.

Requirements of a Scientific Dataset Catalogue

There are 3 major requirements of a scientific dataset catalogue. Dataset descriptions must be:

- entered;
- retrieved; and,
- be understandable.

Getting data descriptions in

In our experience, building a system which enables users to enter their dataset descriptions is relatively straightforward. Normally a computer application is developed which has some form of user-friendly graphical user interface which is designed to minimise the effort involved in capturing the information.

Unfortunately this is where the effort usually stops. The result is that considerable resources are expended but the organisation invariably finds that the initial interest by the scientists to participate soon dissipates.

The challenge, however, is in motivating scientists to document their datasets. Some reasons why a scientist are not interested in documenting datasets include:

- documenting datasets is a tedious task;
- the location and quality of the datasets are already well known to the scientist;
- documenting keeps the scientist away from doing 'real' work (ie science);
- a phone call to colleagues will effectively facilitate locating new quality datasets; and
- there is minimal recognition for spending time to document a dataset.

Consequently, documenting a dataset is a low priority task that is rarely done. This apathy towards documenting datasets is a primary reason for scientific datasets catalogue projects failing.

The key challenge, therefore, is to develop an environment in which describing or documenting datasets is seen to be a priority and worthwhile task.

The dataset publishing concept

Building a dataset has become a highly technical and exacting task with the widespread adoption of computer tools such as Geographic Information Systems, Statistical and Modelling tools. The development of a dataset could easily consume 6 to 12 months of an individual's time. To be rewarded for this effort requires the researcher to publish a scientific paper in a recognised journal. The published paper becomes the mark of achievement and the recipient uses this recognition to further their career.

We recommend that documenting datasets be treated the same way as publishing scientific papers.

The creator of the dataset is the author. The dataset publisher is responsible for providing guidelines for publication, including the requirement to document the dataset. The dataset editor checks that submitted datasets conform to those guidelines. The dataset reviewer would provide an independent check on the validity of the dataset and the appropriateness and correctness of the description.

The process of publishing a dataset would therefore be familiar to anyone who has worked in a science based organisation and would contain the following basic steps:

- the dataset author prepares their dataset ready for publication in accordance with the guidelines provided by the dataset publisher;
- the author submits the dataset to the editor;
- the editor checks for conformance to the guidelines and sends a copy of the dataset and the accompanying documentation to a reviewer;

- the reviewer will validate that the dataset and its description are correct - this may involve requesting modification of the dataset and/or its description;
- if necessary the dataset author will carry out necessary modifications required by the reviewer and editor; and
- the dataset is accepted for publication.

The dataset is now a citable reference for which the author receives due recognition. As with printed scientific papers, knowledge of the dataset's existence must be publicised.

The World Wide Web is one medium with enormous appeal in that a rapidly growing body of scientists have access to this Internet facility and it is ideal for organisations to publish digital datasets or catalogues of their digital data. Of course other publications that would traditionally list published journal articles could also include lists of published datasets.

The ultimate accolade would be some score of how many other scientists used the published dataset. The Citation Index approach to 'scoring' published papers could be extended to cover the usage of reference material including scientific datasets.

The role of dataset publishing in an organisation

One of the consequences of the above concept is that dataset authors can be identified and the published datasets form part of the productive output of the organisation.

In most science-based organisations the number of papers published still dominates the process of receiving reward, including promotions within the organisation. Published datasets form an equally important role in these organisations and hence recognition for their production should receive a similar status to published papers. This will require a significant cultural change.

By implementing a dataset publishing system, an organisation can establish and maintain a scientific dataset catalogue as part of its normal activities. This approach is much more positive than a decree from management that dataset documentation must be completed. If there is adequate reward through merit promotion and peer recognition then convincing scientists to participate will be a matter of informing them of the opportunities.

The organisational benefits of dataset publishing

The above approach is beneficial for individuals who are producing datasets as they will receive due recognition. The organisation as a whole will also benefit enormously from a well maintained catalogue of the datasets produced by the organisation. Scientific productivity will improve, dataset sales will increase and there will be much better indicators of productive effort in the organisation.

If the scientific dataset catalogue becomes linked to the organisations success then it will serve a useful role in meeting that success. If not then the process tends to become marginalised, will eventually cease to function and all the benefits lost.

Management should therefore strongly support the dataset catalogue activity as it is in their interests to do so. Getting management support is cited as a common requirement for success and we believe that it is just as important in this case as in others.

Getting dataset descriptions out

It is one thing to create a dataset catalogue, but how do we ensure that people will use it? In our experience, there are six key requirements which need to be satisfied. The dataset catalogue must:

- be complete;
- be easy to use;
- contain the right information;
- be accurate and therefore credible;
- be available; and
- be publicised.

catalogue must be complete
A dataset catalogue's usefulness is greatly increased if it is complete. For example, where an organisation has documented every dataset in its possession, and no records are returned in response to a user query, then the user is confident that the relevant dataset does not exist in the organisation. If, however, the dataset catalogue is incomplete, even by as little as one or two datasets, the user can never be certain whether or not a useful dataset is held by that organisation.

Within a single organisation, it is conceivable that documentation of all essential dataset assets of the organisation can be achieved and maintained. Dataset catalogues which span across organisations or accumulate information from several different organisations are very difficult to achieve. The purpose of the dataset catalogue in each component organisation may be quite different and therefore their structure and content may vary widely between the organisations.

The traditional approach has been to develop standards so that, in the case of dataset catalogues, a common set of terminology and structure is used in all catalogues complying to the standard. Where this has been imposed by a top-down approach there has been reluctance from the participating organisations to be cooperative.

The important part of the exercise is to ensure that each organisation complies to some standard which is itself documented. If catalogue information needs to be exported from one organisation to another then an appropriate mapping can be carried out using the documentation of the standards in use by each organisation. The task of developing a multi-organisational catalogue is therefore largely one of translating between standards.

catalogue must be easy to use
The user who is using the catalogue must find the required information quickly and easily. The total time taken must be measured in seconds rather than in minutes or hours. In addition, it should not be necessary for the user to receive extensive training before they can use the system. The catalogue is after all a tool which is used to locate and access the datasets required for a particular purpose.

To achieve this, the system that manages the user query of the catalogue requires an intuitive, simple, and visually pleasing interface. To met these requirements, a windows-based graphical user interface is essential. If the system is not fun to use, users will tend to avoided it at all cost.

Scientific datasets frequently have a spatial component. Consequently it is mandatory that the user can search for datasets on the basis of their spatial location. The best way to achieve this is for geographical selection to be carried out by defining points on a map using a mouse or other pointing device.

catalogue must contain the right information
A catalogue that contains inappropriate or incomplete information will not be used. Sufficient information must be present to enable the user to determine if the dataset will be useful for their particular purpose. Determining what information should be recorded in the first place is a difficult task. Each dataset type (eg., soils, vegetation, bore holes, satellite imagery, photographs) potentially has a different set of information that could be recorded. The catalogue must therefore be flexible enough to accommodate this variation.

Indirect quality information can play an important role in judging the usefulness of a dataset. For example, the author's name may convey a quality status to the dataset and a well written abstract may imply that the dataset has been carefully collected and managed.

The content of catalogues has largely been determined by those who classify and categorise information. The utility of a catalogue, however, depends on the relevance of the information that is retrieved to the person making the query. Relevance depends on such factors as the background knowledge of the user, their level of expertise and area of interest as well as the context of the query. These will be very different from those of the person charged with describing the dataset.

Work undertaken in the information sciences field suggests that relevance is a dynamic factor changing every minute as the user extracts information from the catalogue and the context of the query is modified. The content of the catalogue must therefore be defined in terms of the requirements for retrieving information rather than those for classifying information.

catalogue must be accurate and therefore credible
The information present in the catalogue must be accurate. If the user finds that a dataset description is inaccurate or incomplete then the user will view the catalogue as a whole as having low credibility.

Many users of reference systems such as dataset catalogues 'test' the veracity of the catalogue by looking for something with which they are familiar.

catalogue must be available and publicised
The catalogue must be readily accessible. The proliferation of computer networks should enable everyone within an organisation to access their organisation's catalogue as well as catalogue for other organisations.

People must know that the catalogue exists and understand what it can be used for, and how to apply it to their work. This may require an educative process which should be linked to productivity improvement and the success of the organisation.

Understanding the dataset description
Probably the greatest impediment to the successful implementation of a dataset catalogue comes from the inability of the user to correctly interpret the dataset description. A common complaint is that the dataset description misleads the user. This problem is one of the most difficult to solve.

A scientific dataset is generally collected for a specific purpose. The dataset describer emphasises the attributes that are considered to be relevant and important in terms of the purpose for which the dataset was collected.

The potential user of the data may wish to use it in a manner which is quite different from the original purpose. The dataset describer cannot anticipate every potential new usage.

The potential user may miss the dataset, because either the description is inadequate, or the user is unable to perceive its utility from the description provided. This problem is extremely difficult to solve, due to the inherently subjective nature of humans documenting datasets.

The only approach that seems to be feasible at this stage is to try to get the originator of the dataset to describe as fully as possible the nature of the dataset, its restrictions and the purpose for which it was intended.

In the future, more objective techniques must be established, which draw upon the information contained within the dataset itself to provide the description. Computer-generated visualisations of datasets is one example of a more objective representation of a dataset.

Conclusion

The problem of getting datasets to be adequately described must be tackled at an organisational level. We have suggested that the dataset publication concept be adopted with the consequent recognition of the process as being important to the organisation and dataset publication being used as a basis for recognition and promotion.

The difficulty of getting and maintaining dataset descriptions should be alleviated by the dataset publication concept.

There is a need to develop means to describe datasets in an objective way to bridge the gap between the original purpose for collecting the dataset and the potential purpose and context of the query.

AN INTEGRATED SPATIAL INFORMATION SYSTEM WITHIN THE COOPERATIVE RESEARCH CENTRE FOR AUSTRALIAN MINERAL EXPLORATION TECHNOLOGIES

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CRCAMET, c/- CSIRO DEM

Abstract - The Cooperative Research Centre for Australian Mineral Exploration Technologies (CRCAMET) has, as a primary objective, the dramatic improvement of airborne electromagnetic (AEM) technologies for exploration in areas of inhomogeneous conductive regolith cover. To help achieve this goal, the Centre is establishing a comprehensive integrated spatial information system with links between its GIS, RDBMS, image processing systems and the more sophisticated 3D modelling and visualization tools. A particular challenge to CRCAMET is the requirement to examine 2D/3D section/volume data (for example, EM conductivity-depth sections or volumes, drill holes, modelled geology) in conjunction with 2/2.5D spatial data (for example, regolith maps, radiometrics, magnetics, topography). The benefits of integrating datasets from disparate sources arising from the synergistic use of information systems technologies provide opportunities for improved data analysis and cartographic output. However, increased emphasis is placed on issues relating to the design of the databases, database management and an understanding of the problems and opportunities associated with the management of the system.

INTRODUCTION

The Cooperative Research Centre for Australian Mineral Exploration Technologies (CRCAMET) has the dramatic improvement of exploration technology for Australian conditions as a primary objective. The priority for the CRC is the development of airborne electromagnetic (AEM) exploration techniques and their application in areas of inhomogeneous conductive regolith cover. Specific objectives include the evaluation of AEM data for geological information relevant to mineral exploration, the development of software for the modelling and semi-automated interpretation of EM data and the design of new, cost effective, EM systems.

Improving the effectiveness of EM methods in regolith-dominated terrain requires an understanding of regolith characteristics and their spatial variability in three dimensions. This information will enable the better modelling and interpretation of EM data sets. Realising these objectives requires the availability of relevant spatial information systems to assist in the handling, integration and display of a diverse suite of data, including AEM images and located data; other geophysical data sets such as magnetics and radiometrics; geological sections and maps, drill hole data and point observations on regolith characteristics. A particular challenge to CRCAMET is the requirement to examine 2D/3D section/volume data (eg. EM conductivity-depth sections or volumes, drill holes, modelled geology) in conjunction with 2/2.5D spatial data (eg. regolith maps, radiometrics, magnetics, topography). Spatial information systems having this flexibility and functionality require development as they have value in assisting the evaluation and application of EM techniques in Australian conditions.

To that end the CRCAMET has embarked on the development of an integrated spatial information system (SIS) to support its research activities in a number of project areas. An integrated geoscience spatial information system (GSIS) with links between information technology (IT) systems currently in use across the CRCAMET is the ultimate goal.

The spatial information system is based on the ArcInfo geographical information system (GIS) and is supported by the Oracle relational database management system (RDBMS). Links are also being provided to other software packages, particularly image processing and 3D modelling and visualization software.

SPATIAL INFORMATION TECHNOLOGY SYSTEMS

In the past, decisions about the choice of data processing software have been largely driven by specific and immediate needs without significant regard to data sharing, networking and data integration. Data sharing and data integration are now seen as important issues, as is the need to maximize the use of costly data in order to benefit from the value-adding that data integration can bring.

At present the CRCAMET uses a number of systems to handle spatial data. Each of these systems uses a different method to represent the data and the relationships that exist between the data. Data held on some of these systems can, in many cases, be combined, leading to the real benefits arising from the synergistic approach being used. In other cases data sharing between systems can be a considerable problem and we all appreciate care must be taken when planning processing strategies prior to integration. It is not uncommon for different data to conflict to some degree. For example, regolith mapped as vectors can conflict with the regolith as revealed by TM or radiometrics imagery.

While the GIS is capable of integrating almost any data, it might not always be the most efficient means to arrive at the desired result. Easy transfer of data between applications would allow the CRCAMET to take advantage of the best tools for any specific task.

In essence the problem is one of developing efficient, easy links between different processing environments. However, successful integration of the wide variety of digital and analogue geoscience datasets available to the CRCAMET also requires a detailed understanding of the data, their relationships and proposed uses.

THE NEED FOR STANDARDS

The acceptance and use of standards within a GSIS are essential to its effective and efficient design and management. Some of the benefits of using standards include the easier exchange of spatial data within and between systems, the easier integration of GSIS with other systems, the ability to appraise data for fitness of purpose, and optimization of scarce resources. Standards are essential when automating the management and presentation of information. We are all aware that integration of data demands standards. Corporate standards are essential for an integrated system. These corporate standards become the means by which information can be used without the loss of data or accuracy.

A CORPORATE GSIS DATABASE

In these days of cheap and simple data communication, it is feasible to have data located at different physical locations and yet have it organized and managed as a single database. Blind adherence to the concept of a highly structured business notion of what constitutes an "enterprise-wide data model" (Savage, 1994) is not advocated for the CRCAMET. Rather, an evolutionary approach encompassing a distributed, not centralised, data custodianship is advanced as the preferred option.

However, there are some serious implications raised by this scenario. For example, it is imperative that similar standards are maintained at all locations, that the development of GSIS across the CRCAMET sites is coordinated, and that the links between the CRCAMET participants and between the CRCAMET and other relevant organizations are maintained.

DESIGN OF THE GSIS DATABASE

The implication of a corporate database is that there is a single database design against which all corporate applications are designed and run. However, achieving this goal requires a design for the database that will accommodate all applications across the CRCAMET. The specifications of the database design ensure that the data are suitable and in the appropriate structure to support the applications

Data dictionary

The data dictionary defines all map layers whether polygons, lines or points, attribute files, data items, attribute look-up tables, data relate structures, coding and so forth. No widely accepted data standards or structures currently exist for digital geoscientific data in GSISs. The complex nature of the information held by the CRCAMET means that simple tabular attribute tables are not appropriate and that more complex relational structures are necessary.

Map accuracy

In the context of maps, accuracy can be defined as the closeness of results of observations or estimates of graphic map features to their true position. Mapping accuracy standards are generally stated as an acceptable error that must be not be exceeded and the proportion of measured features that must meet certain criteria. The CRCAMET follows the recommendations of a recent US standard (Reynolds and others, 1992) that proposes that accurately located features should be within 12 metres of their true position at a scale of 1:24 000. This is half the tolerance of both US and Australian topographic maps. The standard also recommends that 5% of all points in a database should be tested.

File naming

The importance of standard naming conventions for all GSIS coverages cannot be over-emphasised given the current ease of transferability of files across operating systems. This should be able to differentiate between data types, project, geographic projection, version number and so forth. The CRCAMET's preference is to use the 8.3 notation. Meaningful names are given to coverages to a maximum of seven characters. The eighth character is reserved for a suffix representing editing processes and projection information.

Directory structures

A consistent approach to the organization of the GSIS databases is obviously of great benefit to all concerned as it assists data management and project coordination. The CRCAMET structure includes a directory or work area for each project to hold datasets that are common to a specific project. Each work area includes subdirectories, as appropriate, which contain component datasets and other files. A separate directory holds datasets and other files common to more than one project, for example, AMLs, projection files, common base maps and so forth.

Map projections

All data within a GSIS are, by definition, geolocated. In Australia this referencing system is usually either by geographic coordinates or by Australian Map Grid (AMG) coordinates. Normally one might consider storing all data geolocated to the AMG coordinate system. However, it may be more appropriate to store the data in geographic coordinates because of the problems encountered when a project area crosses two AMG zones.

However, Australia is moving onto a new geocentric datum reference system on 1 January, 2000, but this change began in 1994. The datum is a reference system that has as its origin the Earth's centre of mass and is the best fitting reference surface for the whole earth and provides direct compatibility with GPS. All new maps will be printed with reference to this datum. For this reason the CRCAMET has chosen to geolocate all spatial data in its GSIS with reference to the Geodetic Datum of Australia.

Error assessment

The output products of GSIS often bear little resemblance to any one element of the original data used to construct the output product. The GSIS modelling operation will produce error levels at least as great as that of the most error prone dataset. GSIS modelling can also introduce errors of its own. It should also be remembered that every map contains inherent errors based on the nature of the map projection, construction techniques and symbolization of the data (Vitek and others 1984). Operational errors can also be introduced during data entry, data manipulation, and data extraction.

If the type and number of errors are not specified for any map product, potential users may draw false or invalid conclusions about the map product (Aronoff 1982). The objective of the CRCAMET is to present test data in such a form that the map users can interpret the results and thereby have the option of rejecting any data source for their specific application.

GSIS DATABASE MANAGEMENT

Technical standards are only part of the solution for improving the effectiveness of a spatial information system. Management standards, although harder to develop, are also crucial.

Metadata - data about data

The importance of metadata is being realised in the GSIS community. In essence metadata is a definition of the history and lineage of data that resides in a spatial information system. Metadata can range from basic descriptive information through to precise detailed information about the digital data. If users are informed of the data source and its attributes they can then make appropriate decisions on how, or even if, to use the data. Metadata is the foundation on which the long-term usefulness of the GSIS is built.

At the basic level all datasets being input or originating in the CRCAMET's GSIS are accompanied by a descriptor file that contains information about the spatial and attribute data for the coverage. These descriptor files, which stay with the coverage throughout its life, are based on the FINDAR system (Shelley, 1992).

Data quality control procedures

Quality control procedures, both automated and manual, have been designed to check the positional accuracy, attribute accuracy, completeness, correctness and integrity of a spatial dataset. Documentation of data sources, data input procedures and quality control measurements allow users to assess whether the data are appropriate for their applications. They also protect the user from misinformation.

Audit logs and traces

Also central to the quality control process is the use of audit logs or traces that facilitate documentation of the data layers as they are modelled and analysed. Normally this is done using a manual, forms-based system. However, more recent developments include specialized applications software. Once the data sources are documented all commands and inputs are recorded so that for any layer in the database the sources and transformations used to derive that layer can be interrogated.

Exchange and transfer of data

Because of the diversity of users of digital data within the CRCAMET, some of whom will require access to similar and/or the same datasets, a system is in place to manage the exchange of data between end-users. The system ensures that the required data are received from the data custodian in an appropriate format with supporting documentation complete with information relating to the confidentiality of the data. Any translation of data undertaken to meet the requirements of the end-user is done according to the CRCAMET's recommended standards and procedures. All end-users requesting and using the same dataset receive updates of that dataset as and when they become available. This ensures that all end-users are using the same vintage dataset in their analyses.

The coordination of the transfer of data between data custodians and end-users is vital in ensuring that all end-users have access to the same vintage data and are aware of any confidentiality restrictions placed on the data, the quality and utility of the data, and so forth.

A CORPORATE RDBMS

The CRCAMET has chosen Oracle to be its main RDBMS. In order to standardize the way in which point data are recorded, the CRCAMET has chosen to follow the lead taken by AGSO and use the OZROX database SITES table for all locational data (Ryburn and others, 1993). OZROX is logically linked to other databases via the SITES table.

Multiple environments

The CRCAMET has recognized the importance and advantages of multiple environments within Oracle. Two environments, Test and Production, have been developed both of which reside on the same platform. The Test environment is where all development and testing are performed such as designing new databases or modifying existing ones. The Production environment is where only production work is carried out. Obviously this is a tightly controlled environment. Once a system has been fully tested in the Test environment it can then be transferred to the Production environment.

The main advantages of multiple environments lies in the fact that production work is isolated from that of development and maintenance work, thereby increasing the stability and integrity of the data in the Production environment, that development, maintenance and testing of the programs occur in a non-critical database, and that much higher levels of data integrity can be maintained, both in the data and data structure.

Data custodianship

Once project datasets have been incorporated into the CRCAMET database, the issue of data custodianship will have to be resolved. Each dataset must have a custodian who is responsible for the validity and accuracy of the data. While the database manager inspects all proposed alterations to the database for errors that could disrupt the database, the data custodian must ensure that proposed alterations are valid and accurate from the standpoint of data consistency. The database manager will grant each custodian a role that will allow them to control who alters their data.

Backup and recovery

In order to maximise user confidence in the database, a thorough database backup strategy is required. The type of backup strategy dictates how much data can be recovered in the event of a system failure (power failure, media crash and so forth). Strategies range from no backup system where the database is not recoverable at all, to a full backup strategy where the database is recoverable up to point-of-failure. The CRCAMET currently has the resources to put in place a full backup strategy which includes a periodical full off-line database backup (for example, once a week), periodical incremental backups (for example, once a day), and periodical dataset exports (for example, twice a week).

DATA INTEGRATION

GSIS, image processing and 3D visualization systems have, over the years, developed separately into distinct, yet related, disciplines. Each has its specialized functions, but with the rapid developments in computer hardware and software it has been demonstrated that integration of data between these systems has much to offer.

At its simplest, data integration is the ability to display different types of vector data with a geo-referenced image as a backdrop. Simply putting together the datasets for a given project can require an unexpected level of expertise and time. It has been estimated that at least 50% of any project involves building the GSIS database for that project. One of the strengths of GSIS is that it allows users to relate one dataset to another. However, the issue of the integration of 3D data has not been fully addressed by GSIS.

Many authors have made suggestions as to the nature of integration. Ehlers and others (1989) have addressed this question and have identified three levels of integration. The standard approach to integration of 2D/2.5D data such as surface geology and digital elevation data and 3D sub-surface geophysical or geological data has been the comparison of map-view image interpretation with a selection of sub-surface cross-sections. The relationship between surface and sub-surface information can be better understood through quantitative 3D modelling. Combined modelling of these data can prove a far more effective technique for discrimination of sub-surface regolith structures as interpreted from AEM data than a map-view approach.

ARC/INFO AND/OR ARCVIEW?

The structure of the CRCAMET's integrated spatial information system has been designed with regard to the requirements and needs of end-users. However, consideration was also given to the environment in which the end-users visualize and analyse their project data.

End-users should have access to an easy-to-use tool that gives them the power to visualize, query and analyse their data spatially. They should not necessarily need (or indeed want) to know how to create geographically referenced datasets. They require the data they receive from the GSIS managers to be in a form suitable for visualizing and analysing within a desktop environment.

Although ArcInfo is to be established as a major component of the CRCAMET's GSIS, it is inappropriate to expect end-users to become proficient in its use. There are a number of products on the market that fill the role required by end-users. ArcView is recognized as a desktop GIS product that is thoroughly compatible with ArcInfo and which brings together GIS, desktop mapping, and multimedia, with DBMS and business graphics. As such it is highly suitable for adoption by the CRCAMET as its primary analytical tool.

CONSEQUENCES OF AN INTEGRATED SPATIAL INFORMATION SYSTEM

Classifications and terminology

Traditionally, information in regolith-related disciplines has been recorded using subjective, and often ill-defined terminology (Lenz and Pain, 1992). Moreover, it is evident that most field geologists use the existing terminology in an inconsistent manner that precludes the comparison of data, site and unit descriptions.

To be able to share data in a corporate GSIS, it is essential that field geologists agree on the classifications and terminology to be used. A number of basic guidelines should be recognized (Lenz and Pain, 1992). The database must be constructed so it can be used with a GSIS, standard terminology must be used, only agreed terms can be used, and the terminology must fit into a hierarchical scheme and be assigned codes accordingly.

These guidelines should be construed as applying to all data, not just regolith. For example, petrophysical, geochemical, mineralogical and other databases must be constructed within the above guidelines. At present, only AGSO's databases (of those of the CRCAMET participants) follow the above guidelines. As a consequence, the CRCAMET is using the AGSO data model with the associated classifications and terminologies as a suitable basis for the development of its own databases.

Field data collection

Since it is anticipated that all data collected as part of CRCAMET will be entered into the GSIS databases for modelling and analysis, it is appropriate to consider the issue of field data collection standards.

Most data collected by a geoscientist is recorded during fieldwork and entered it into a field note book. It can be argued that there are inherent weaknesses in this manual method of field data collection, especially when the intention is to set up a computerized database as part of an integrated spatial information system. It is evident that considerable time and effort must be expended in order to retrieve selected and meaningful data. The major problem to be addressed is how to rapidly retrieve, manipulate and analyse the large amount of field data collected as part of the field mapping process. Such a system, must be systematic, formatted but still flexible enough to allow for the geologist's individuality.

To achieve this the Geological Survey of WA (GSWA) and AGSO have developed site data entry forms for use in the field. These forms are easily bound together into a convenient field note book. Relational databases containing these data have also been established, GSWA uses Microsoft Access while AGSO uses Oracle. The two databases are very similar in the way in which they are structured, in the organization of tables, and in the type of data collected. Both recognize the one-to-many relationships and the logical relationships of the field site data. Data exchange between the two organizations is therefore straightforward.

With the imminent establishment of major projects the CRCAMET has decided to develop a more appropriate method of field site data collection that lends itself to rapid incorporation into the CRCAMET's spatial information system.

Training

Development of the GSIS also involves developing the skills and resources of the users so that they can apply the technologies. Training is needed to ensure that the system receives effective use. The types of training (orientation, application, administration) will depend not only on the needs and aspirations of the individuals, but also on the establishment of an effective integrated spatial information system that is compatible with existing systems such as those of AGSO and the GSWA.

ACCESS TO GEOSCIENTIFIC DATA

Geoscientific data are held by state and federal agencies, exploration and mining companies, universities and libraries. The Richards Review of AGSO identified the need for a major program to develop a nationwide network of interconnected physical and electronic geoscientific data holdings.

The @ngis initiative by AGSO (Berman, 1994) has been designed to link the diverse collections of Australian geoscientific digital and physical data holdings. The model supports access to both centrally managed data, and data under custodianship in public, private and educational institutions; AARNet will provide the links to the World Wide Web. AGSO is currently developing a World Wide Web server, standards for metadata, a directory and query system, and links to the information systems of ERIN and NRIC.

@ngis is to be a collaborative effort, with all organizations holding geoscientific data and information being invited to participate. The lead role is being performed by AGSO, which has been given funds to help organizations become an integral part of the system. Apart from AGSO, a number of geoscience databases and information systems are also being developed by the State and Territory Geological Surveys, CSIRO, industry and educational institutions, libraries, museums, and Cooperative Research Centres.

The @ngis initiative will offer considerable benefits to the CRCAMET in terms of being able to access the vast stores of currently inaccessible geoscience data. It is in this regard that the CRCAMET is developing and maintaining links with the @ngis initiative and drawing on the expertise of AGSO in developing its own node on the @ngis network.

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Using GIS for Mineral Potential Evaluation in Areas with Few Known Mineral Occurrences

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Abstract: Geological agencies are increasingly being asked to participate in land use disputes to identify what the mineral potential of a region is, and to put a dollar value on the mineral wealth contained therein. As many disputed areas to be evaluated contain only a few occurrences or deposits, traditional statistical methodologies developed for the evaluation of the mineral potential of a region are not really applicable. Most statistical methodologies require the presence of a reasonable number of occurrences to be able to generate a valid assessment of the geological factors surrounding a group of deposits or occurrences. For this reason, we have chosen a conceptual approach for mineral potential evaluation in areas with few known mineral occurrences that relies on 3 separate, but integrated steps:

Step 1: involves developing a knowledge of Australian ore deposits as parts of regional scale 'mineral systems' in which the essential ingredients considered necessary for the formulation of a particular deposit type are expressed in terms of criteria mappable digitally within a GIS. Ore deposits need to be considered first as regional to district scale 'mineral systems', and then broken down into local, district and regional scale mappable criteria. The 'ingredients' considered essential to the formation of a deposit (*e.g.*, oxidised fluids, temperature, host rock composition) must also be translated into features that can be displayed within a GIS (*e.g.*, alteration zones, metamorphic grade, presence of reactive rock types, etc.). Within a 'mineral system' it is possible to apply 'ore deposit models' to search more specifically for known deposit types.

Step 2: entails the development of high quality geoscience GIS packages that express these mappable geological criteria as searchable attributes.

Step 3: comprises the development of methodologies for analysing the above GIS packages for mineral potential that does not rely on the presence of a minimum number of deposits present so that the resultant analysis can be regarded as statistically valid. The GIS analysis techniques developed have three different, but complementary methodologies. The first methodology is essentially an expert system that relies on a digital database of characteristics known to occur around major mineral systems and deposit types. The second methodology allows the user to interactively develop maps that highlight areas considered to have potential to host mineral deposits. The third methodology examines zones around known areas of mineralisation (or anomalous areas considered to have potential) and then determines the specific geoscientific expression of these areas in all themes[1] within the GIS.

INTRODUCTION

Geographic Information Systems (GIS) offer an ideal tool for mineral resource assessment. They have an inherent capacity to integrate many disparate geoscientific data sets, thus facilitating the prediction of the metallogenic potential of any region. Not only do they offer the opportunity to independently validate geoscientific data, they also allow data from other conflicting land use issues such as environment, heritage and culture to be integrated simultaneously to enable more rigorous comparisons of the competing issues.

GIS can also become an 'expert' in its own right. To date, some land use debates simply involved opposing 'expert witnesses' each determining the potential of an area based on his own personal interpretation of the available data. Their 'subjective opinions' were presented as highly technical, complex hard copy reports: rarely was the raw data used in compiling the 'opinion' made publicly available. The opposing 'opinions' were inevitably challenged more on the technical merits of the opposing 'expert', rather than on who was technically correct. In contrast, GIS can allow a more formal approach to land use evaluation and validation of 'opinions'. In any dispute, the data used

1 In this paper we are using 'theme' for layers or coverages within the GIS and 'attribute' to describe the individual fields or items within each theme.

to make interpretations and valuations of the mineral potential within a GIS can be made much more readily available. In addition, the steps utilised in developing interpretations as to why a region has (or has no) mineral potential can be documented. These steps can then be followed in any inquiry, resulting in the interpretations being more open to public scrutiny.

As has been exemplified in some of the more recent contentious land use debates (*e.g.*, Coronation Hill (Wyborn *et al.,* 1990), Shoalwater Bay (Anonymous, 1993)), there was often only a small number of known deposits and prospects within the disputed area. Hence the mathematical, multivariate techniques that rely on the statistical analysis of known mineral occurrences (*e.g.,* Bonham-Carter *et al.,* 1990; Harris, 1984) were not appropriate. Indeed, in any area if there are sufficient known deposits for a statistically valid analysis to be carried out, then the land surface is probably so modified that it is unlikely it will be considered for alternative land uses which highlight natural geographical features such as national parks and world heritage areas.

For this reason, we have developed a conceptual methodology for analysing the mineral potential of areas with few known mineral occurrences (Wyborn and Gallagher, 1994, Wyborn *et al.,* 1994a; Jaques *et al.,* 1994) which requires three separate, but integrated steps. The first step is the development of a knowledge of Australian ore deposits with their essential ingredients expressed in terms that can be mapped within a regional to district scale GIS. The second step involves the development of high quality geoscience GIS packages that can search for the occurrence of geological factors considered essential for the formation of most mineral deposit types. The third step comprises developing a conceptual methodology for analysing the GIS packages for mineral potential that is not driven by a statistical analysis of a minimum number of deposits and occurrences.

It is our aim in this paper to outline how we have approached these three steps and how we are integrating them. We will discuss some advantages of our approach and also outline some possible future directions.

STEP 1. DEFINING ORE DEPOSIT MODELS AS PART OF REGIONAL MINERAL SYSTEMS THAT CAN BE MAPPED WITHIN A GIS

The first step involves the consideration of particular styles or types of deposits in terms of specific combinations of mappable components that can be located within a GIS. As most ore bodies have cross sections of less than 3 km^2, they do not offer a particularly large target for an exploration program. They are also difficult to locate within either a district scale (up to tens of kms) or regional scale (up to hundreds of kms) GIS. Fortunately most ore deposits result from the exceptional coincidence of common geological processes, many of which are mappable on district to regional scales. In reality, the ore deposit is the central feature of a regional to district scale mineral system which was defined by Wyborn *et al.* (1994a) as *'all geological factors that control the generation and preservation of mineral deposits, and stress the processes that are involved in mobilising ore components from a source, transporting and accumulating them in more concentrated form and then preserving them throughout the subsequent geological history'.*

For GIS analysis of the mineral potential of an area, it is critical to think of the actual ore deposit itself as a minor part of a regional scale system (Fig. 1). The total mineral system can be broken down into 6 major components:

1) energy to drive the system,
2) ligand source,
3) metal source,
4) transport pathway,
5) trap zone (and ore deposit location),
6) outflow zone.

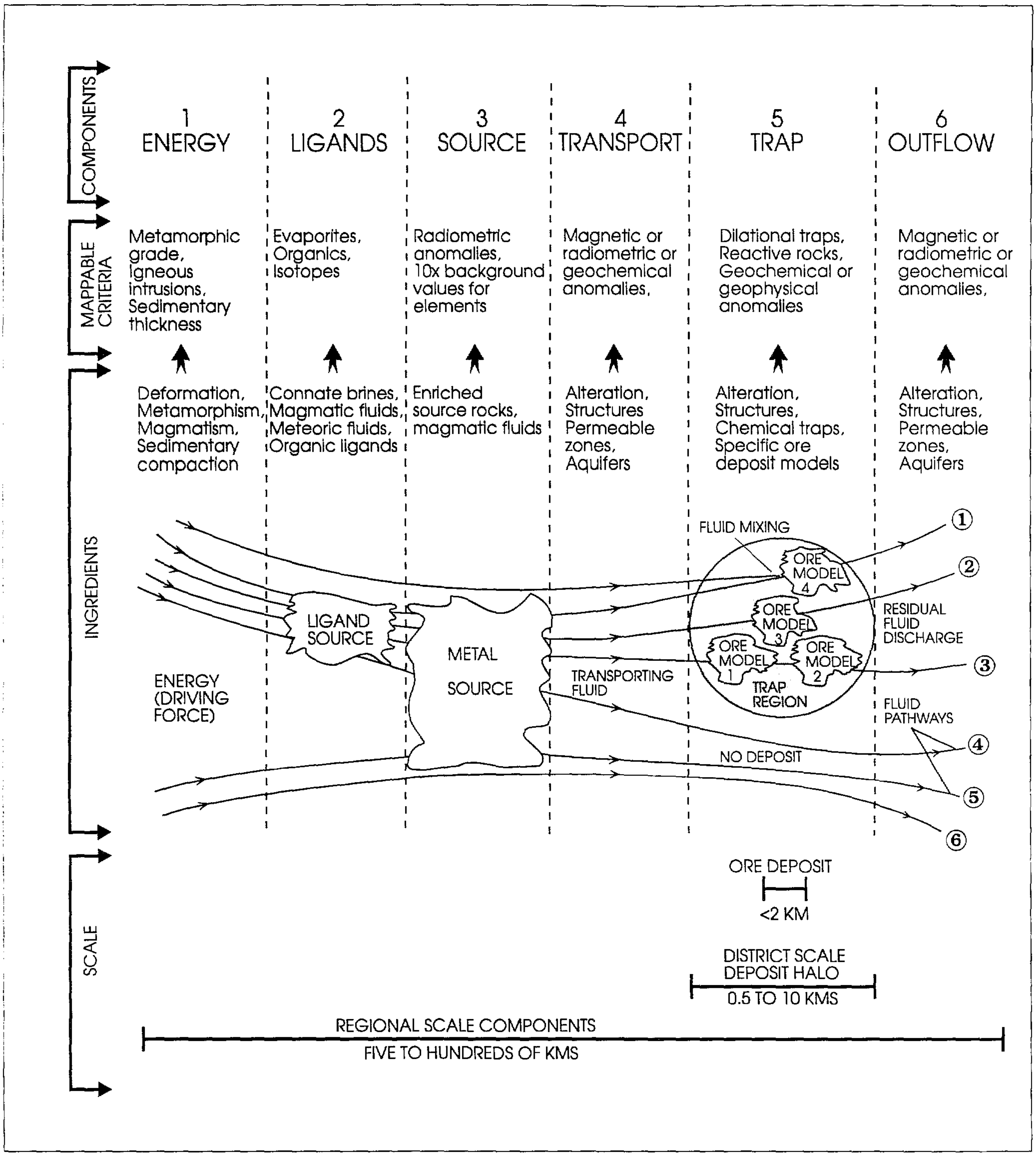

Figure 1. Schematic diagram of the components of a mineral system (based on Figure 1.1. of Heinrich *et al.*, 1989)

The mineral system concept focuses on the total ingredients necessary to form a deposit and it is important to emphasise that the mineral systems approach is different to searching for specific ore deposit models (*e.g.*, Cox and Singer, 1986). Most ore deposit models only define component 5 - the trap zone. Ore deposit models also tend to focus on criteria that are mostly on the local, or at best district scale, and do not really consider the regional scale components critical to understanding the controls on ore location.

Mineral systems are mappable on varying scales, some much larger than others. For example, the mineral system associated with the large tonnage, typically Proterozoic shale hosted base metal deposits (Mount Isa, HYC) must have operated over hundreds of kilometres. In contrast, the mineral system associated with a porphyry copper deposit would be much smaller and measurable over tens of kilometres.

The distinction between an ore deposit model and a mineral system is also critical to GIS analysis as the mineral systems concept is more easy to portray within a regional scale GIS than are specific ore deposit models. Once this broader picture is accepted, it then becomes obvious that within each mineral system, there may be several 'ore deposit models' applicable. For example some of the essential ingredients of a volcanogenic massive sulphide mineral system are a continental margin or rift setting, active volcanism, original water depth > 200 m and a magmatic heat source to drive a hydrothermal system. Within that system, there are many ore deposit models and styles that more detailed exploration could focus on *e.g.,* the Hellyer, Scuddles, Woodlawn, Mount Lyell styles of Large (1992). The differences in ore deposit styles (models) are dependant on parameters such as permeability of the footwall volcanics, the composition of the volcanics, the temperature of the ore fluids, the depth of sea water, and the fO_2 and aH_2S of ore fluids (Large, 1992).

Another example is the unconformity-style of U-Au-PGE mineral system. All variants are associated with major faults which allow highly oxidised, high salinity brines in the cover sequence to react with compositionally varying trap rocks in the basement sequence (Mernagh *et al.*, 1994). If the trap rocks are enriched in a reductant, then the deposit produced is a U dominated deposit such as Jabiluka. If the trap rocks are enriched in K-feldspar, then an Au-PGE dominant deposit with minor U will develop such as at Coronation Hill. That is, the differing subtleties between the two deposit types are determined by local factors within the trap component of the mineral system.

Each of the components of a mineral system have first to be considered in terms of potential 'ingredients' that can make up that component. For example, Component 1 - the energy to drive the system can be a metamorphic or magmatic event, whilst Component 5 - the trap, can be a dilatant fault structure or a trap rock rich in carbonate or both.

As shown in Fig. 1 the 'ingredients' considered essential to the formation of a deposit (*e.g.,* oxidised fluids, temperature, host rock composition) **must** then be translated into mappable criteria that can be displayed within a GIS (*e.g.*, alteration zones, metamorphic grade, presence of reactive rock types, etc.). This is not always easy to do. For example an essential ingredient of the unconformity-style of U-Au-PGE mineral system is highly oxidised, meteoric, low-pH, high salinity brines at about 140 - 200°C. Fluid inclusion studies have been used to identify this ingredient within the trap component but an extremely extensive fluid inclusion database would be required to map this fluid on a larger scale. Even if such a database is available, it may not be all that reliable, as the appropriate fluid inclusions may not have been trapped, or if present they may be masked by the presence of many other generations of fluid inclusions. A more realistic way to map the fluid composition, is to assume that because the fluid has to reach at least 140°C, it would have to descend to a minimum depth of 4.5 kms (assuming a normal geothermal gradient of 30° C/km), and that the rocks through which the fluid passes would have to be oxidised, or else precipitation of U-Au-PGE would have taken place. Thus one ingredient of this mineral system would be the presence of a major thick, neutral to oxidised rock package (as aptly describes the Kombolgie Formation, the unit that lies above the major deposits in the Alligator Rivers Uranium Field (Needham, 1988)). The presence of this unit is detectable within a properly constructed GIS package.

In addition to defining the key ingredients essential for the formation of each mineral system, it is useful to define the minimum major geological features associated with each. These minimum geological features required help define a tract. A tract is defined as theqrea which contains the *'principal geological ingredients that are needed for a specific mineral system'*. For example if the focus of the mineral potential evaluation exercise was to estimate the number of potential stratiform PGE deposits likely to occur in a specified region then from within the GIS only 'tracts' which contain layered mafic-ultramafic intrusions need to be extracted for further analysis. In contrast, if the aim of the exercise is to evaluate the potential number of granite-related Au ± base metal mineral deposits then the 'tract' of land extracted must contain not only the fractionated, oxidised I-type granites (both exposed and those subsurface plutons delineated by geophysics), it must also contain areas up to 5 kms from the granite contacts (Wyborn and Heinrich, 1993).

However, no matter how much care is taken developing GIS relevant mineral system descriptions, it is wasted unless the care is taken to develop metallogenically-relevant GIS packages - our next step.

STEP 2 - THE DEVELOPMENT OF GIS PACKAGES WHICH HAVE INTERNALLY VALIDATED, METALLOGENICALLY RELEVANT THEMES

As pointed out by Wyborn *et al.* (this volume), it is unfortunate that many digital maps and databases packages do not readily lend themselves to even the most simple analytical techniques. Digital databases and maps from the same area and produced by the same field programs often do not integrate. For example, a mineral deposit database states that an exposed ore body is hosted by Formation X, and yet the point representing the deposit plots in a polygon of Formation Y. Linear features which represent metallogenically important features such as faults are stored in such a way within the digital maps that makes effective metallogenic analysis difficult, if not impossible (Wyborn *et al.,* this volume).

The fundamental requirement for a GIS to be used for metallogenic analysis is as accurate a version of the geological map as is possible, with all relevant features stored with searchable attributes (Wyborn *et al.,* 1994c). A GIS to be utilised for metallogenic modelling must also, at a minimum, contain primary geological themes (geology, geophysical images, satellite imagery), point databases (physical rock properties, geochemistry, mineral deposits, etc.), as well as a set of associated derivative themes formed by combining primary themes (solid geology, metamorphism, tectonic province, *etc.*). Metallogenically important information on rock units such as the presence of hematite, magnetite and graphite, the age of the unit, its porosity, *etc.,* can be attached to the base map by simply adding expansion tables to the primary data sets. For granites, these attributes should also describe granite type, degree of fractionation, oxidation state, *etc.* whilst for mafic igneous rocks there should be indicators of the degree of sulphur saturation, Cr content, Mg number, *etc.* Each attribute in these expansion tables should store information in a simple format. For example, for the mineralogy data, we use the numbers 0, 1, or 2 to indicate whether the mineral is not present, present in trace amounts or abundant, respectively (Wyborn *et al.*, 1994c).

To speed up metallogenic analysis, it is often easier to set up a series of specific themes to facilitate measuring the distance from a particular feature such as a granite boundary, faults or anticline axes as a series of themes which have concentric buffers at varying distances from these specific features. Other special themes that need to be prepared are those which highlight the orientation of a specific feature. For example, many mineral deposit types are controlled by faults of a specific orientation and the faults can be classified according to their general trend direction by calculating and storing slope values for arcs providing they have nodes at all of the important changes in direction (see Wyborn *et al.,* this volume).

Once the data sets are collated they must then be internally validated before any metallogenic modelling is applied. It is essential that all point data fit into the correct polygons and that all duplicate arcs have identical geographic coordinates. Once the total GIS package has been prepared and validated, it is then ready for undertaking metallogenic analysis. The authors wish to point out that preparation of these validated GIS packages is not trivial, and can take many months.

STEP 3 - THE DEVELOPMENT OF METHODOLOGIES FOR EVALUATING MINERAL POTENTIAL WITHIN GIS.

In developing our approach we have assumed that there are insufficient ore deposits within the region being assessed to utilise methodologies that rely on the statistical analysis of known mineral deposits. To effectively evaluate any tract of land for a particular mineral system we have developed three different modules: Specific modelling, Interactive modelling and Generic modelling. To fully evaluate a region we believe all three modules are necessary.

(i) The **Specific Modelling Module** contains a suite of programs that extract from a set of themes those regions that satisfy all geological parameters considered essential for the formation of specific mineral system and its associated ore deposit types. It is essentially a simple expert system, with the data on the individual deposits built up from related work on the total regional mineral system associated with major known Australian examples. Because the definition of the reference deposit is digital, then the comparison with unknown areas to find a known deposit is more authoritative. That is, the project is not relying on an 'expert' opinion that components of the geology of the area being assessed is similar to the regions around major Australian ore deposits: the GIS independently makes the comparison. The two main limitations with this system are firstly, that a deposit has to be defined and its characteristics determined for this methodology to work and that new deposit styles such as Olympic Dam would not have been located this way. Secondly, the GIS of the region to be evaluated must be constructed in a fairly rigid manner, with all themes and attributes named identically to those of the expert system.

Methodology[2]***:*** Specific modelling is a simple menu-driven utility containing a routine for each ore deposit: each routine embodies the formation criteria for a deposit style, coded as selection statements from standard data sets. When the user chooses a deposit style from a menu list (Fig. 2), the utility determines which regions meet its criteria. The only other factor over which the user has control is the region of interest, for example Mount Isa or Pine Creek.

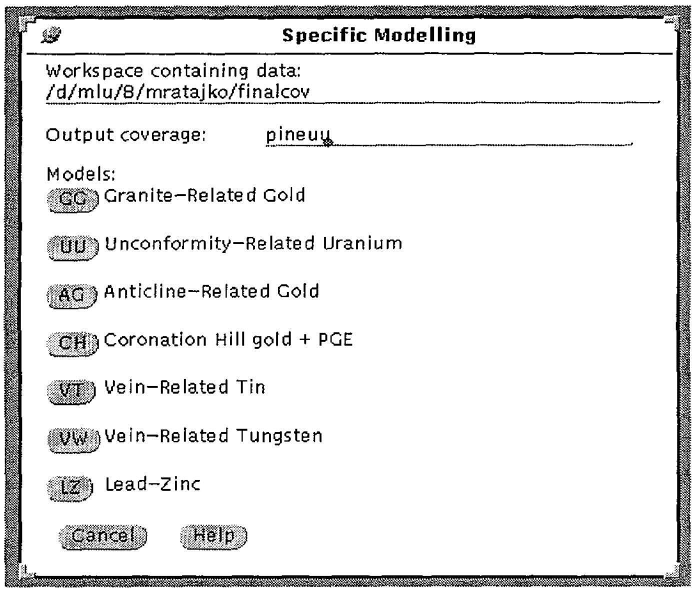

Figure 2. Simple menu-driven utility for analysing for a specific deposit model. All the user has to do is to select the deposit type, and name the output coverage.

(ii) The **Interactive Interrogative Modelling Module** allows the user to interactively develop his own model by defining specific search parameters within a set of specified themes: the GIS is then used to locate and combine those areas that meet the selected criteria. This methodology gives the geologist concerned the ability to define unusual rock types that may make up an unrecognised deposit type. The effectiveness of the model created can be tested by overlaying any known deposits. In this module the mineral deposits are used to test, rather than drive the analysis. This methodology is intuitive and does not rely on known deposit types.

Methodology: Since this is implemented in ArcTools, views contain a list of all potential data sets for the modelling (grids or polygon themes) as well as reference themes. Modelling is carried out on grids: images should be converted into grids before being included in views. Polygon coverages are rasterised when they are placed in the Modelling list.

The Interactive Interrogative Modelling Module has the following component processes:

1) listing of the pixel and attribute values of themes at selected locations (Fig. 3).

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2 All of these methodologies were developed in Arc/Info. Some of the terminology used may be specific to this package.

2) creation of a modelling list (Fig. 4) which is compiled by applying selection criteria to each of a set of themes (Fig. 5). This modelling list contains binary grids: areas satisfying the criteria are set to 1, other areas to zero.
3) combination of data layers to produce a new grid whose pixel values reflect the measure of compliance of the input themes with the user's criteria.

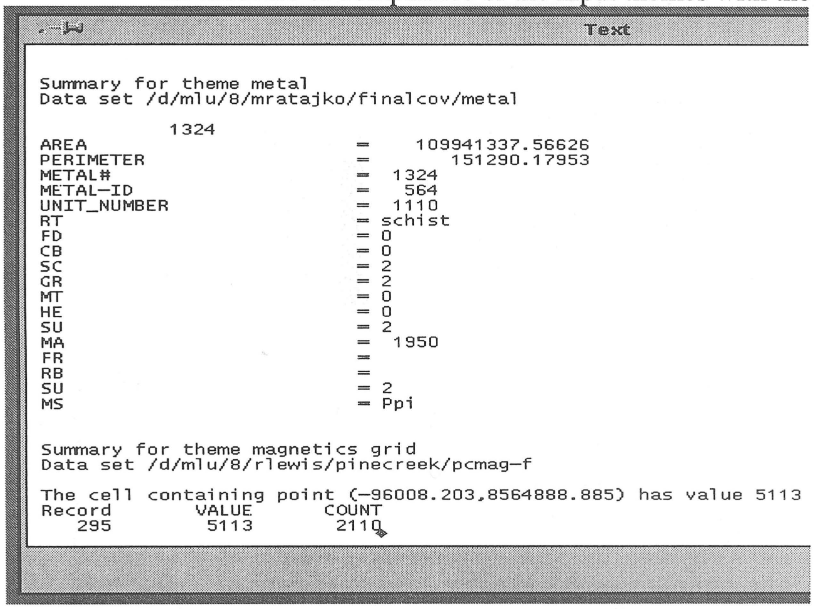


Figure 3. The summary list that is displayed of the pixel or polygon attribute values for each theme in theme selected.

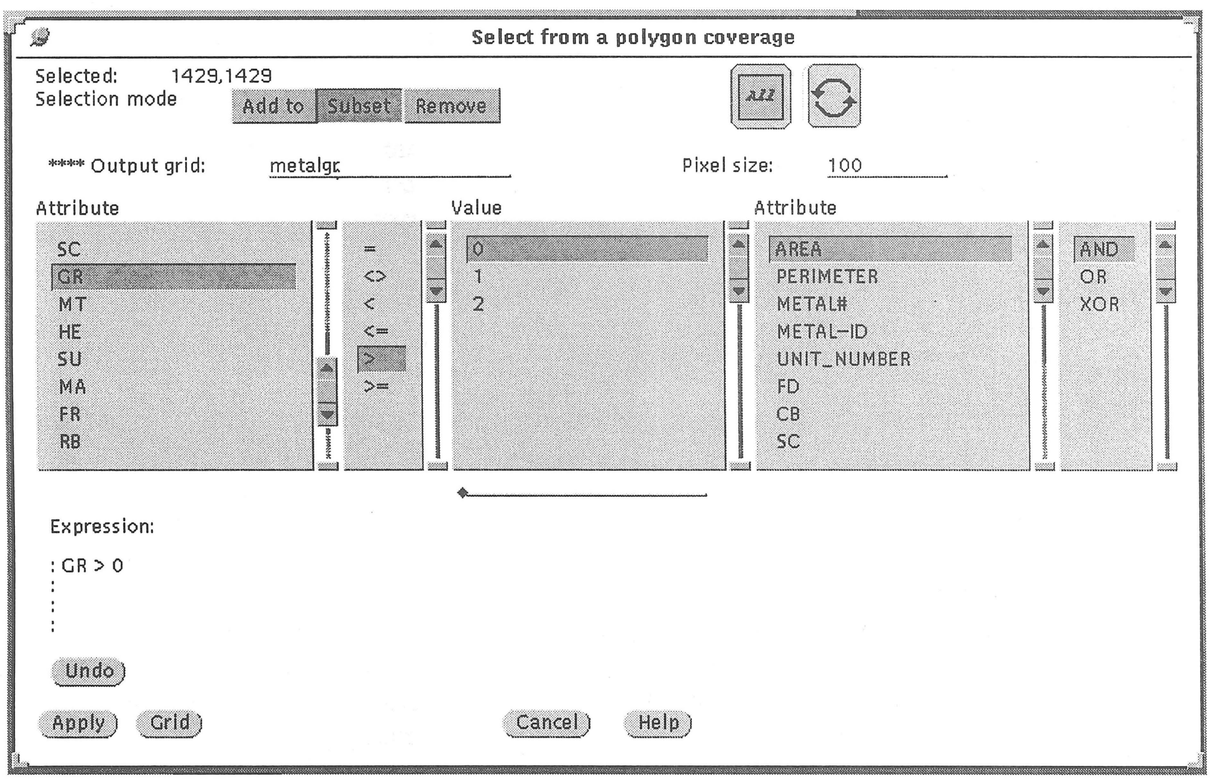


Figure 4. Interactive Interrogative modelling theme manager.

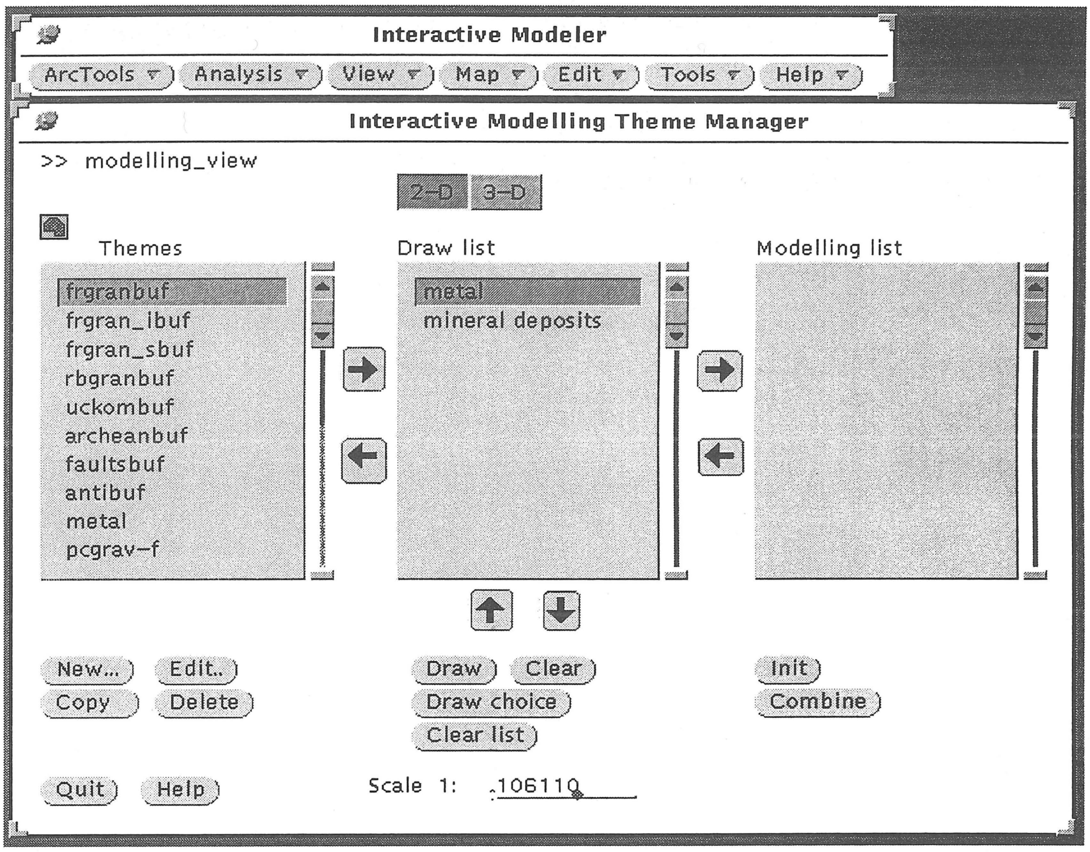


Figure 5. The menu used to create the binary grid from a theme by applying user criteria.

(iii) The **Generic Modelling Module** can examine known areas of mineralisation or important geophysical anomalies within the GIS, and then determine the specific geoscientific expression of the ore deposit(s) and anomalies on all specified themes. This methodology is independent of the user.

Methodology: This is implemented in ArcTools. Again, the modelling is carried out on grids and images which should be converted to grids and polygon themes are rasterised during the modelling. The Generic Modelling Module has the following component processes:

1) the creation of a list of all potential themes sets for the modelling (grids or polygon coverages) as well as reference layers (Fig. 6).
2) for a polygon coverage, a small menu prompts the user for the name of the output grid, the cell size and the attribute within that theme which is to be used to derive the raster (Fig. 7).
3) selection of point locations of interest (*e.g.*, mineral deposits or locations selected using the mouse). Points are added cumulatively until the clear button is used (Fig. 9).
4) selection of a buffer radius used to create areas of interest around point locations (Fig. 8).
5) listing of the pixel ranges of all grids in the buffer areas, as well as common values of other attributes attached to the grids (Fig. 9).
6) selection of all other areas in the data layers with the same pixel or attribute values, and creation of an output binary grid marking them. Areas satisfying the criteria are set to 1, other areas to zero. Where a grid in the modelling list has no attributes besides values and count, the pixel range in the buffer areas is used to determine all other identical pixels (Fig. 9).
7) where a grid has a list of attributes with constant values in the buffer area a checklist is presented of those attributes and values in a menu. The user has the choice of enforcing an exact match of all attributes or choosing to use only a subset of the attributes in creating the binary map (Fig. 10).

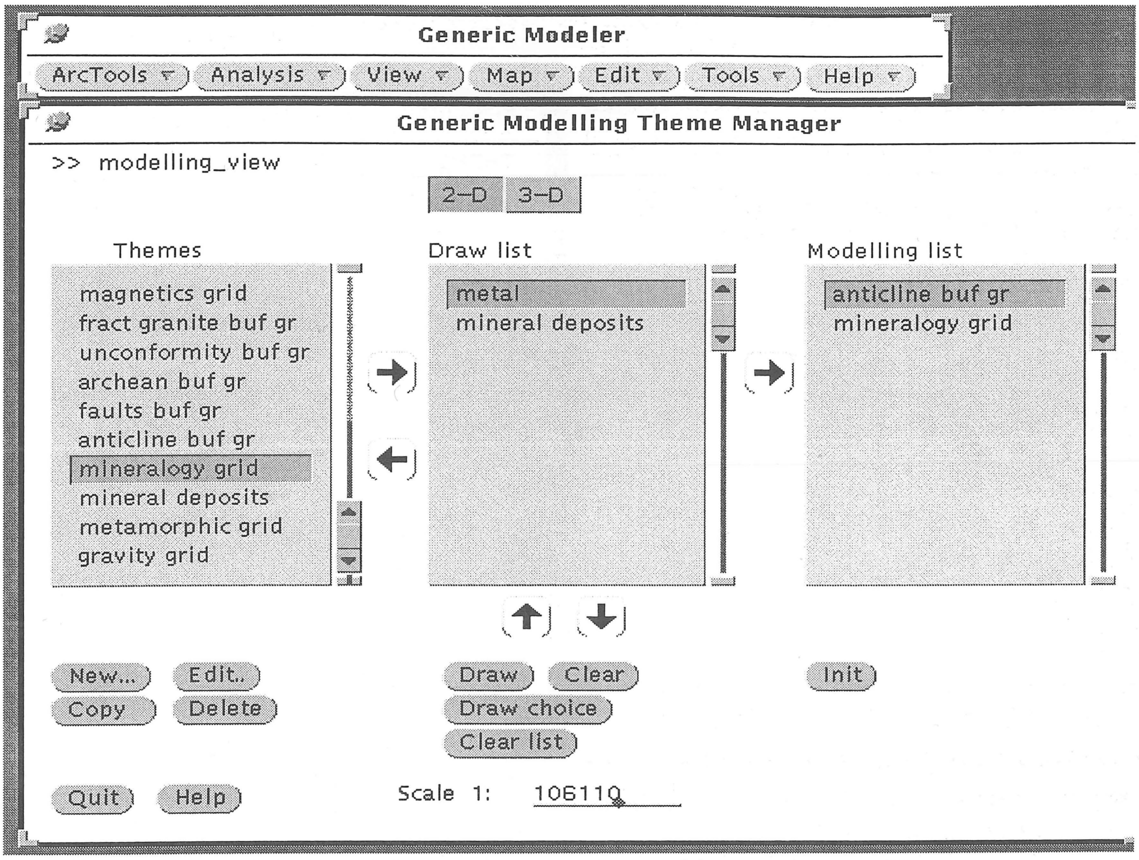
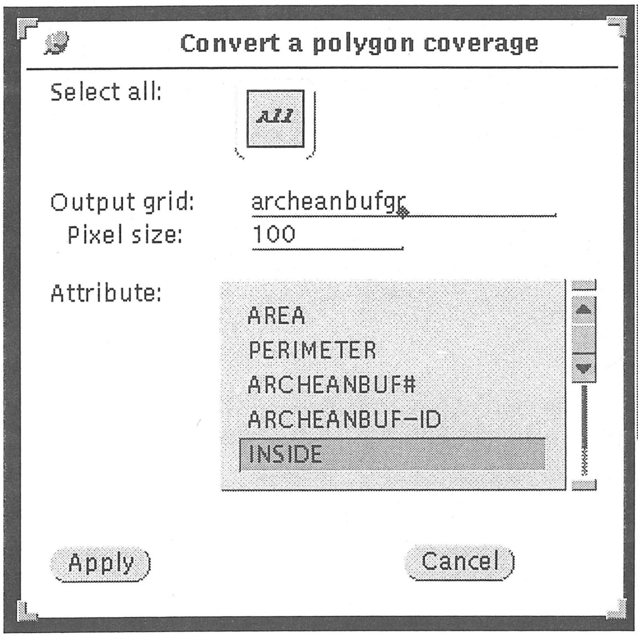


Figure 6. Creation of the list of themes that are to be used in generic modelling



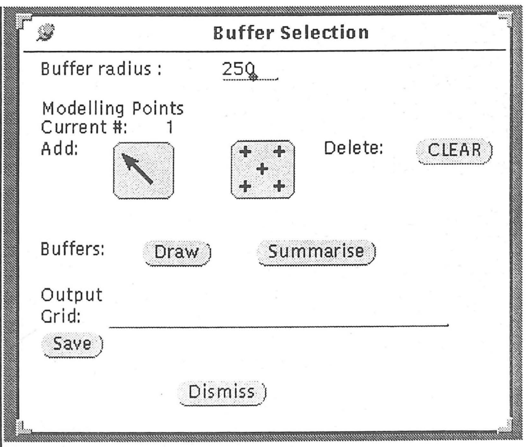


Figure 8. Menu used to select the buffer radius, chose the points for analysis and name the output grid.

Figure 7. Menu used to convert polygon themes to a grid

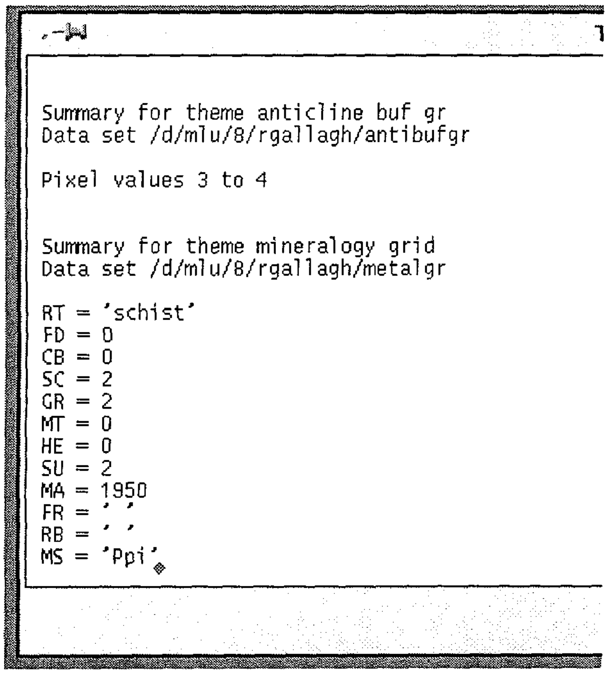


Figure 9. Summary list of all common attributes within the buffers around points.

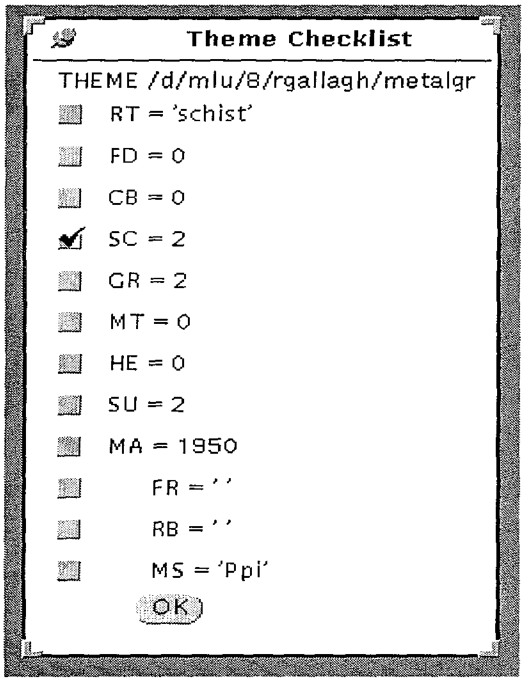


Figure 10. Menu used to select attribute values that are to be used to create the final grid.

DISCUSSION

The conceptual approach to metallogenic modelling developed in this paper has advantages in being able to determine the mineral potential of poorly explored or greenfields areas. By using the three integrated steps there is a greater flexibility, particularly as governments are increasingly asking for land use planning issues, which areas are unlikely to ever have potential for any mineral deposits whatsoever.

However, to be effective, conceptual metallogenic modelling requires careful preparation of properly attributed geoscientific GIS data sets. It also requires the complementary development of the documentation of Australian mineral systems and their associated ore deposit models expressed in terms of mappable features that can be determined in the related GIS packages.

This whole process of thinking of ore deposits as part of regional scale mineral systems and breaking down their components into essential ingredients and then translating these into mappable features requires a fundamental rethink on how ore deposits are described and defined. The approach has to be multidisciplinary and needs observations on all facets of geoscience. However, this rethinking of ore deposits as components of mineral systems must take place in association with the groups that are developing the metallogenic GIS packages (including the field mappers). There needs to be constant interaction between the two groups so that the ore deposit people can advise the field mappers of which criteria are likely to be observed around specific ore deposit types (*e.g.* alteration zones mappable with regional geophysics, specific host lithologies) and the GIS people can work out ways of portraying these features within a GIS such that they can be effectively analysed.

The application of this integrated approach can make the definition of the areas least likely to have mineral potential much more scientific. In many cases areas with largely undetermined mineral potential are being 'written off' purely on the basis of our current, generally superficial understanding of the geology in the areas surrounding known deposits. Methodologies to define sterile ground that rely on comparing a given area with areas surrounding known mineral deposits are suspect for two reasons. Firstly, as emphasised by Wyborn *et al.* (1994b) few geological maps presently available, digital or otherwise, highlight the distribution of metallogenically important features such as the presence of graphite, magnetite or carbonate. Alteration zones are rarely noted even when their presence can be mapped from regional geophysical data sets, and important characteristics of granites which indicate metallogenic potential are rarely recorded.

Secondly, and the main reason why the comparative methods with known deposits are flawed, is because new deposit types are still being identified. For example, the world class Olympic Dam deposit still does not seem to fit any known deposit type (*e.g.,* Cox and Singer, 1986) and its initial discovery was a result of the application of a model which has since been shown not to apply (Smith, 1993). The discovery of relatively low temperature PGE deposits associated with the unconformity style Coronation Hill Au-PGE-U deposit is another example (Noranda Pacific, 1985). The presence of these PGE elements was totally unknown during the early 1960s when the Coronation Hill mine operated as a uranium ± gold mine.

In other cases, deposit styles considered to be well understood are constantly being re-examined in the light of new knowledge or new technology, with factors once considered important being downgraded, and new areas then being targeted for a particular deposit style that had previously been ignored. An example of this is the Century zinc-lead deposit of the northern Mount Isa Inlier which is located within the Lawn Hill Formation (Waltho and Andrews, 1993). In many models for exploration for stratiform Pb-Zn deposits this unit had not been considered prospective because of the absence of evaporite minerals and pyrite as well as its young age relative to the age of known host rocks for other major shale-hosted base metal deposits. Once these specific criteria were no longer considered essential for the formation of major stratiform base metal deposits then areas of the Lawn Hill Formation adjacent to major fault structures became prime targets.

All these examples highlight the inadequacies of evaluating land exclusively using expert systems based on known deposits. However, for properly constructed metallogenic GIS packages it is possible to more effectively target those areas where components of many mineral systems exist. For example, in a properly constructed metallogenic GIS, all occurrences of reactive rock types can be targeted, all known areas of fractionating granites noted, and alteration zones detected. Therefore, if an assessment has to be made, the important ingredients of major mineral systems can be highlighted even if there are no known deposits in this region.

Future directions in our approach include:

- improving the generic and interactive methodologies to allow for weighting of the individual components so that individual criteria considered to be more important can be weighted relative to those criteria not considered to be important.
- expanding the generic and interactive methodologies to allow searches based on a polygon type, rather than a point.
- developing 3-D methodologies for even more effective metallogenic analysis. Currently, we can only assess potential in 2-D, when 3-D applications are required. For example, current methodologies for assessing the mineral potential surrounding granites classify only those areas within x km horizontally of a granite boundary. The ability to analyse vertically is also required.
- utilising one-to-many relationships in a mineralogy table to incorporate time so that changes in porosity, permeability, abundance of magnetite, carbonate etc with time due to influences of diagenesis, metamorphism and deformation can be incorporated.

CONCLUSIONS

Our approach to metallogenic analysis is multidisciplinary and multifaceted. It requires the integration of many geoscience disciplines. Our methodology is comprehensive in that it allows for comparison between known areas of mineralisation outside of the area being assessed; it also enables the user to build up his own picture of potential mineral deposit sites as well as determining the criteria around known deposits or anomalies. We believe that comprehensive metallogenic assessment of an area requires all three methodologies. Although our approach is biased towards understanding resource potential of regions with few known mineral deposits, it has applications for the exploration industry who are generally trying to assess whether or not a particular tract of land with no known deposits has potential for a specific ore deposit type. However until digital maps and databases are properly and effectively constructed and until mineral systems and their associated ore deposit models are expressed in terms of mappable criteria rather than in values of temperature, pressure and fluid chemistry, any methodologies developed within GIS for mineral potential analysis will always be limited.

ACKNOWLEDGMENTS

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LANDSTAR - AN AUSTRALIA WIDE REAL TIME DIFFERENTIAL GPS SYSTEM FOR GIS DATA CAPTURE

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Racal Survey Australia Limited

The advent of Geographic Information Systems (GIS) has revolutionised the management of spatial information by aggregating information from disparate sources in a layered structure. The data within the various layers is related by a common reference framework. The power of a GIS comes from the value of the total information being greater than the sum of the individual components to a user.

However it is fair to say that most of the focus and development activity in GIS to date is in the development of sophisticated computer software and complex data structures and very little attention is paid to the integrity of the underlying data. This may be because there is nothing "sexy" about data compared to using the latest computer system. However, it is data that is the main "ingredient" of a GIS system. No amount of sophisticated data processing techniques employed will convert spurious data into a meaningful GIS system. This doesn't mean that the data is necessarily erroneous but that it may be used in a manner for which it was never intended when the data was first captured. For example, data may be captured for a particular application at a certain accuracy but used later on for another application way beyond the accuracy limits of the data because the computer can "zoom" in on a point and show three decimal places for its position.

Data capture methodologies generally fall into three categories. They are:

- i) data from third party sources such as digitising existing maps,
- ii) areal data using techniques such as aerial photogrammetry or satellite imagery,
- iii) point data using ground based survey techniques or satellite positioning technology such as GPS.

It is the Global Positioning System (GPS) which has shown to be a most cost effective and efficient data collection tool for capturing point data for GIS and the focus of this paper.

NAVSTAR GPS (NAVigation System using Timing And Ranging) was developed in the 1970s for the United States Department of Defence (DoD) as a world wide, all weather, 24 hour, 365 days a year positioning system for the military. The Global Positioning System was never designed to be used for civilian positioning but its obvious advantages attracted further research and development by academics and manufacturers with the tacit approval of the US military to become the mature system it is today.

GPS is based on a constellation of 24 satellites orbiting the earth at an altitude of 20,200 km in six orbital planes inclined to the equator at 55 degrees. Each satellite does 2 revolutions of the earth every 24 hours. This means that at any time of the day and at any where in the world a minimum of 4 satellites will be "visible" above the local horizon.

The satellites act as reference points in the sky because their orbits are very accurately monitored by ground stations around the equator. The distance or range from a satellite to a ground station can be determined by accurately measuring the elapsed time it takes a signal to be transmitted by a satellite until it is received by a GPS receiver on earth using the simple formula:

range = elapsed time x velocity   where the velocity is the speed of light

Knowing the range from three satellites to a GPS receiver, the users position can be found as the point where the three distances intersect. One could think of this as swinging an arc with a set of dividers centred on a satellite, with the radius of the arc being the range from the satellite to the GPS receiver on the ground. The arc would be intersected with similar arcs from another two satellites and the intersection point would be the user's position.

The transmitted signal by the satellite contains coded information which "stamps" the time of transmission on the signal (based on the onboard clock in the satellite) which the GPS receiver can read. The GPS receiver knows the time of reception of the signal (based on the clock in the GPS receiver) and the elapsed time can be found by:

elapsed time = time of reception - time of transmission

In reality, the timing of the signal from the satellite to the GPS receiver contains a "clock error" because the clocks in the satellite and GPS receiver will be misaligned. The clock offset can be determined from additional information from a fourth satellite. The "observed" distances or ranges from the satellites to the ground contain this clock error and so are called "pseudo-ranges" and the signals are called "code" data.

When the GPS system was first trialled the accuracy of GPS exceeded the original design specifications of the US military. It was considered a military threat for civilians to have access to accurate GPS positions in real time (as they happen) anywhere in the world. The US military decided to purposely degrade the accuracy of GPS under its policy of Selective Availability (SA) to be within the following limits;

"100 metres 2D RMS at 95% confidence and 300 metres 2D RMS at 99% confidence"

This means that, by the laws of probability, a user's instantaneous position could be more than 100 metres away from the true position 5 % of the time and more than 300 metres away 1% of the time. There is no way the user can tell when this is occurring.

Figure 1 shows the GPS positional error over a 24 hour period with a position being recorded every minute. It can be seen that there are short periods when the error exceeds 350 metres and in the worst case 600 metres.

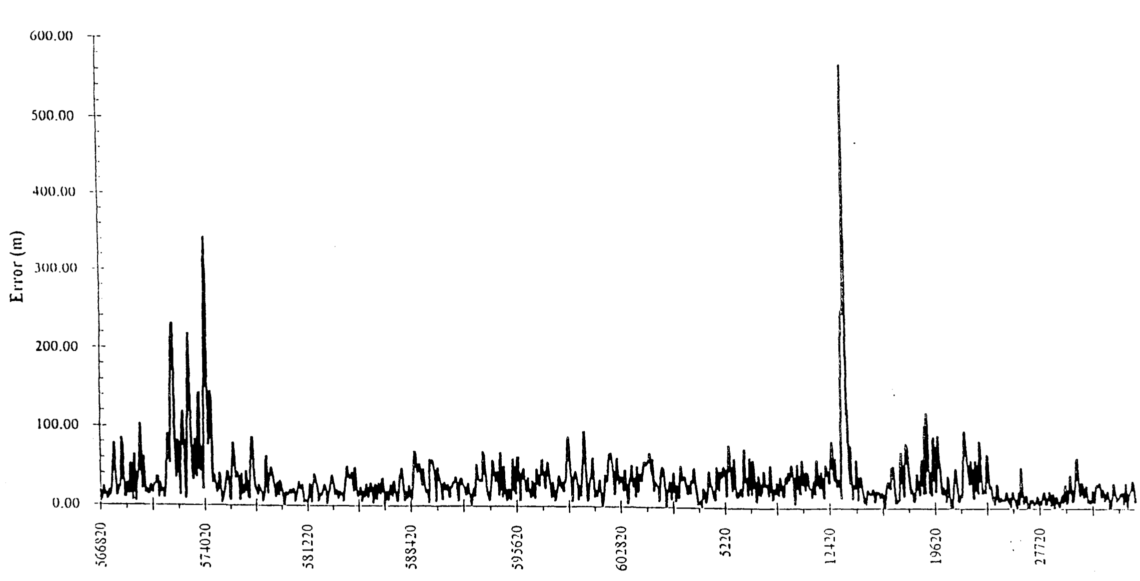

Figure 1 GPS 24 Hour Accuracy Plot (with SA on)

As well as the purposely imposed error under SA, there are a number of other error sources in the GPS system. They are principally the errors in the satellite clocks, the satellite's orbits and propagation error of the signal as it passes through the various layers of the earth's atmosphere (ionosphere and troposphere). The method of Differential GPS (DGPS) can cancel out many of these errors and provide an enhanced level of accuracy for the user.

The principle of DGPS relies on two GPS receivers acquiring the GPS signal simultaneously. One receiver must be on a known point that has previously been surveyed and the other receiver at an unknown location. The unknown receiver can be static or mobile. At the known point the instantaneous GPS total error (SA + clocks + orbits + atmosphere) can be found by comparing the GPS observed position with the known position;

GPS position error = known position - GPS observed position

OR

GPS pseudo-range error = known range - observed GPS pseudo-range

If the determined GPS error is applied at the unknown site, with the opposite sign, the error is minimised and enhanced GPS accuracy is available. The underlying assumption here is that the major error sources in GPS are external to the GPS receiver, are systematic and highly correlated between separated sites. This assumption hold true for sites even 1000 km apart, this being a fraction of the distance to the satellites of 20,200 km. The path of the GPS signal from the satellite to the known point is very similar to the signal path to the unknown point and hence the error will be common and cancel out between sites.

Error Source	Standalone GPS (metres)	Differential GPS (metres)
Satellite Clocks	3.0	0
Orbit Errors	2.7	0
Ionosphere	8.2	0.4
Troposphere	1.8	0.2
Selective Availability	30.0	0
Receiver Noise	0.3	0.3
Multipath	0.6	0.6
User Equivalent Range Error (UERE)	31.4	0.9

Table 1 Typical GPS and DGPS Error Budget

The User Equivalent Range Error is simply the square root of the sum of the individual errors squared and shows the combined GPS error budget.

The DGPS corrections can be applied after the event (post processing) by logging the data of two GPS receivers concurrently at a known and unknown point and processing the combined data on a computer using some proprietary software.

Alternatively, the GPS differential corrections can be broadcast from the GPS receiver on a known point to a GPS receiver on an unknown point using radio links in real time (ie as they happen). The principal disadvantage of radio links (UHF, VHF and HF) are that they are unreliable having range limitations, line of sight limitations and affected by atmospheric disturbance.

The differential corrections can also be broadcast over cellular telephone or on a sub-carrier of FM radio. However these methods are confined to areas where the cellular telephone network or FM radio exists around the population centres and also suffer from slow update rates.

The GPS industry has developed an industry standard format for the broadcast of differential corrections that all the GPS manufacturers have adopted. This is the RTCM SC-104 (Radio Technical Commission for Maritime Services Special Committee 104) format standard. This means that any GPS receiver that is capable of accepting differential corrections in the RTCM SC-104 format can accept them from any source.

The Racal **LandStar** DGPS system broadcasts GPS differential corrections in RTCM SC-104 format in real-time over the whole Australian continent. Racal has established a network of reference stations around Australia which have been accurately surveyed and act as the known points monitoring the GPS signals constantly. The established reference stations for **LandStar** are:

Perth	Sydney
Dampier	Melbourne
Broome	Adelaide
Darwin	Alice Springs
Cairns	

The computed differential corrections at each reference site is sent to the Racal network control centre for validation and integrity checking. From the network control centre the GPS differential corrections, in the RTCM SC-104 format, are uploaded from the Optus centre at Lockridge, WA to the Optus satellite and then broadcast Australia wide to all **LandStar** equipped users. The update rate of the differential corrections is every 2 seconds with a latency (age of corrections) of 2-5 seconds. The accuracy of **LandStar** DGPS is better than 5 metres and typically 1-3 metres with separation distances from the reference station greater than 1,000 km.

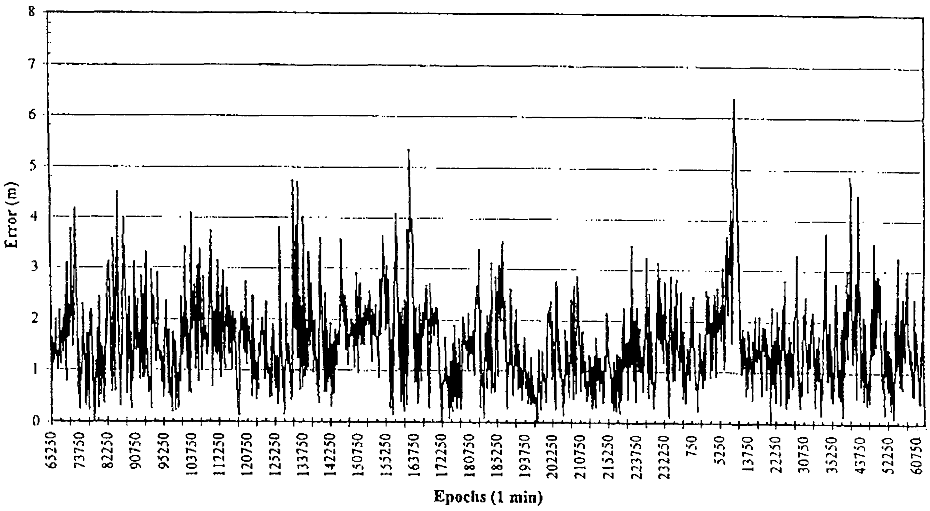

Figure 2 LandStar DGPS 24 Hour Accuracy Plot (with SA on)

It is the accuracy level of DGPS at 1-3 metres that is attractive to GIS users because of the reliability of the positions and the ability to successfully integrate the data with more accurate datasets such as cadastral information, mining tenement boundaries, geological information, drill hole sampling etc.

The principal advantages of **LandStar** DGPS are:

i) enhanced accuracy with reliability 24 hours a day in all weather conditions,

ii) position solution available in real-time, anywhere in Australia,

iii) there is no requirement for user installed base stations and unreliable radio links,

iv) small, lightweight and portable equipment.

The only equipment required by a user is a **LandStar** receiver, antenna and a RTCM capable GPS receiver and you have a portable GIS data collection system that will in an efficient manner collect accurate and reliable point data in the field. This is the basis of a meaningful Geographic Information System.

Plenary Session Report

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PURPOSE

The Plenary session was attended by about 30 people, from government and industry. The purpose of the session was to:

- explore issues that had emerged during the Forum; and
- review developments since the 1992 meeting.

LAST MEETING

A copy of the previous workshop overview paper (Berman, 1992) was supplied, so that those present would be familiar with the themes and issues of three years ago. These were taken as a starting point for stimulating discussion. In summary, these were:

- **Standards initiatives** - at the last workshop, a GGDPAC data standards group convened and sought feedback on proposed geoscience core data classes and attributes;

- **GIS & RDBMS** - a joint software approach to spatial data management was seen as necessary for relating and analysing attribute data and themes;

- **Data models** - although the technology for data integration was now available (at least to 2D), robust models relating GIS themes, cartographic layers, vector/raster data types and database entities were seen as essential to support integration;

- **Data quality** - problems arising in dealing with poorly documented lineage, data matching, different accuracy, scales, projections, classification techniques and digitisation standards among datasets were highlighted;

- **Data exchange** - current standards development (SDTS, AMDEX, FINDAR) to support data exchange was discussed, but it was concluded that in the short term proprietary format translators and compatible data dictionaries would be required;

- **Data providers** - the data pricing policies of government agencies, and the need for coordination in data collection was an issue. New national initiatives to address policies on pricing public good data were foreshadowed.

WHERE ARE WE NOW?

Standards Development Processes

The Plenary group discussed the rate of development of standards. The approach promoted by GGDPAC through the AMIRA mechanism was criticised as being too slow, and not readily lending itself to user testing/acceptance. Unfortunately, unlike government, industry has not backed the project as widely as was indicated initially, which affects the rate of progress. It was pointed out that even the POSC initiative had, to date, taken 30 man-years, and was not completed.

A more radical approach was supported - that AGSO or others should propose and promote new standards, and see how the marketplace reacted. Recent experience to support this approach was seen in outside interest in AGSO's GIS "Red Book", and good demand for field notebooks, often because a disk with codes was also supplied that could be used in other systems.

Feedback mechanisms are essential. The World Wide Web was suggested as a new way of putting coding schemes, definitions, AMLs etc in the public domain easily, and of also monitoring the interest generated (extent of downloading etc). In this way, for example, the tagging line codes developed in Tasmania could be uploaded to an @ngis standards page alongside other coding schemes, and news groups informed to stimulate discussion. Santos mentioned its success in following PPPM and POSC developments through the Internet, and encouraged making metadata catalogues available this way.

There was also an industry view that because of the time and energy involved, standards work should be "chunky", eg doing a well table or treating a stratigraphic unit as one task.

It was pointed out that non-geoscience users have trouble with our standards, eg. Dept Defence acquires digital geological data as an indicator or surrogate, and finds discrepancies in codes or unit names. There should be a base layer digital map. Unfortunately, although there are some 8,300 names in the stratigraphic index, these are not widely used (not promoted well in Universities) - and Cainozoic names have not even been treated yet.

A policy was suggested, requiring endorsement from Chief Government Geologists, that no name should be used on a map unless it has been registered - eg. including terms for lake deposits, laterites etc.

It was noted that there are also problems in mapping informal lithological units that need consideration, and guidelines developed for students. Universities should be encouraged to make their data available, or better catalogued - as is now occurring in UWA. This should be a condition of a research project, and perhaps enforced through ARGC reviews.

Likewise, AMIRA could insist that data from projects is presented or catalogued in some general, consistent manner. Institutional arrangements for research datasets not managed on an ongoing basis by Universities are also required (AMIRA library-like function, or an @ngis role?).

Overall, there was support for continuing with two approaches for standards development - the institutional approach (formal projects through GGDPAC, AMIRA etc, workshops such as this one, and user-group meetings), as well as the more random, evolutionary approach using a continuous forum on the Internet, as outlined above.

Point data compilations

During the Forum, good papers were presented from industry, academic and government speakers on approaches to collecting and treating point data using GIS. Government representatives asked that industry provide more feedback on whether the packaged regional GIS approach was what was required, or could be improved upon.

There was support for these products, but also for the more traditional open file reports, and ASCII datasets to be available.

It was asserted that eventually the GIS coverage would be the basic dataset, accompanied by a digital cartographic coverage; the map should not precede the dataset, and the geological bias should be stronger than the cartographic. Many of the methodological considerations were covered in depth in the Forum, and at the associated Map Production workshop. These statements generated some discussion between cartographers and geologists. Currently, there are varying approaches in the states. This was resolved by noting that the required standard of compilation should be agreed at the start amongst all affected, also taking account of future data management needs; eg. in deciding on whether a fault could be represented in a geological polygon, or required a separate coverage.

The role of GIS

It is accepted now that although GIS may be used for data management, this is not its strength or prime function. Linked database systems have grown in their capabilities and popularity ahead of similar capabilities within GISs. Where GISs excel is in the areas of modelling and visualisation.

It was noted that in larger organisations, where groups of geologists/cartographers operated at arms length, it had taken longer for the balance of professional needs to be accommodated, compared to how smaller project teams had operated in the last few years.

Software functionality

Continuing efforts were noted by geoscientists to get messages to vendors to better develop software to meet discipline-specific problems. Cases were noted of local developers taking the time to research the specific needs of clients - eg at this Forum, and privately. Sometimes smaller packages did not have all the functionality of larger packages, but at least suggestions could be readily incorporated.

Sometimes less widely used packages were superior in some areas, as did not carry "baggage" from older software development code and the need for backwards compatibility. It was noted that government tended to be more conservative in its choice of GIS software, probably because of long-term company viability concerns, and government data custodianship requirements.

It was also noted that some functionality required - such as generalising or "opening" of data exchange formats, the automation of data quality and other metadata, was now being developed in response to customer pressure, competition, and (US) government decrees.

Future Forums

The general question of what was an appropriate forum and frequency for future meetings was discussed. It was noted that strong discussions on GIS/data issues came up at vendor forums such as OZRI. However, such gatherings by their nature disenfranchised others, and were sometimes too specific.

It was mentioned that a first GIS in Mining workshop (21 November 1994) had been organised by BHP Engineering preceding the last AURISA conference (as are many other user group annual meetings). The Australian Urban and Regional Information Association is regarded as the peak general Australian body for across-discipline spatial systems. That workshop had not been well attended, although it was very informative.

Likewise, the Australian Mineral Foundation (AMF, Adelaide) would be holding its National Conference on the Management of Geoscience Information and Data over 18-20 July this year (every 4 years), through the Australian Geoscience Information Association (AGIA), and this could also be seen as a more natural, general forum.

Other, commercially-sponsored specific conferences were also springing up - such as the Oil & Gas Information Technology Conference (Melbourne, 14-15 August 1995).

People noted that this meeting had been much more successful than the 1992 workshop in bringing together people from a range of disciplines working in aspects of SIS, and from the various sectors, who had benefited from the interaction.

Those present decided that the other alternatives were either too board or narrow, and as Goldilocks said, the present Forum was "just right", if held with a two-year frequency. It was also recommended that a section be added for specific vendor papers, which should also be an opportunity to compare approaches and features, and to hear of "roadmaps" for anticipated developments.

REFERENCE

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