Scientific visualisation and 3D modelling applications for mineral exploration and environmental management

John Wilford[1]

Introduction

Complex spatial information for geological, geomorphological, and geophysical studies is generally stored in relational databases and displayed as either discrete (point, line, or polygon) or raster (e.g., satellite and airborne images) datasets. For their analysis and integration, these datasets depend mostly on commercial GIS software operating largely in 2D space — a severe restriction for Earth-science datasets in 3D, or 4D if time is included. Most subsurface information is interpreted and displayed thematically in 2D (e.g., depths-to-basement contour maps, magnetic/bedrock polygons, cross-sections, fence diagrams, drill profiles, and block sections). Subsurface variation and composition is typically poorly depicted on most geological and regolith maps.

Recent advances in GISs and in visualisation hardware and software have fabricated an interactive environment for the desk-top operator to display, analyse, and integrate geoscientific information in a 3D context. AGSO scientists are keeping abreast of these advances, and using computer-generated 3D models and visualisation techniques in several projects to help analyse, interpret, and communicate information for mineral and petroleum exploration and environmental management.

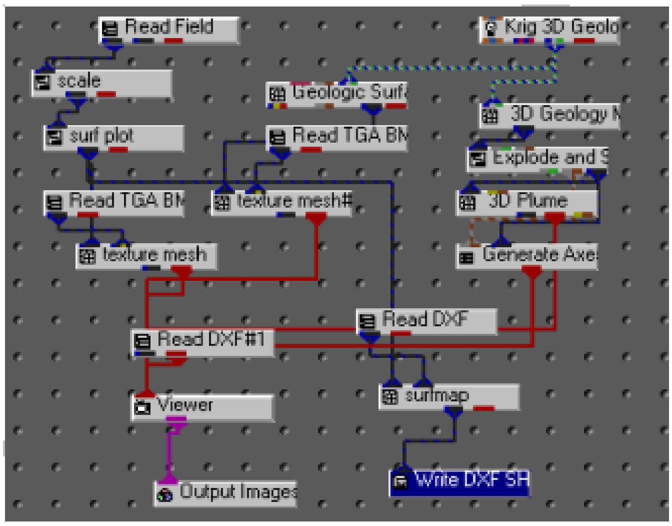

Fig. 17. Data-flow processing network.

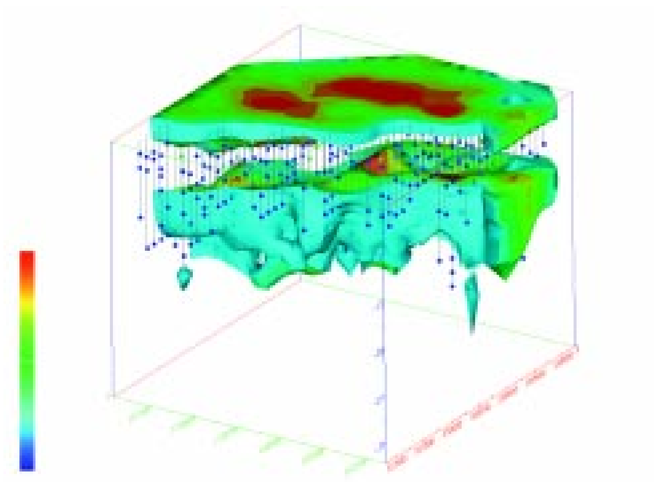

Fig. 19. A 3D regolith model based on drillhole data from the Tanami area. Gold concentrations are combined with the regolith units to better resolve the relationships between the regolith and supergene gold dispersion. Colours from blue to red indicate increasing gold concentration. Drillholes are shown as pipes; geochemical samples, as dots.

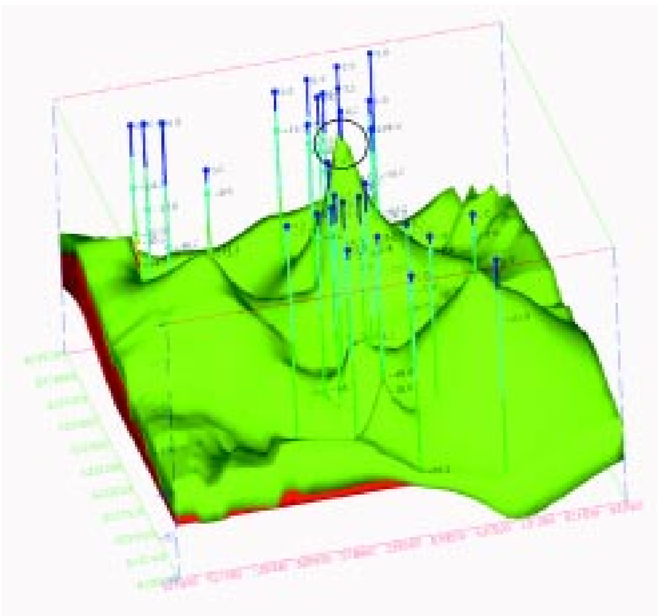

Fig. 18. A 3D regolith block model constructed from drillholes. Vertical pipes mark the position of the drillholes. Inconsistent logging of the drillcore can result in anomalous spikes in the isosurfaces (3D surface of equal value) as indicated by the circle.

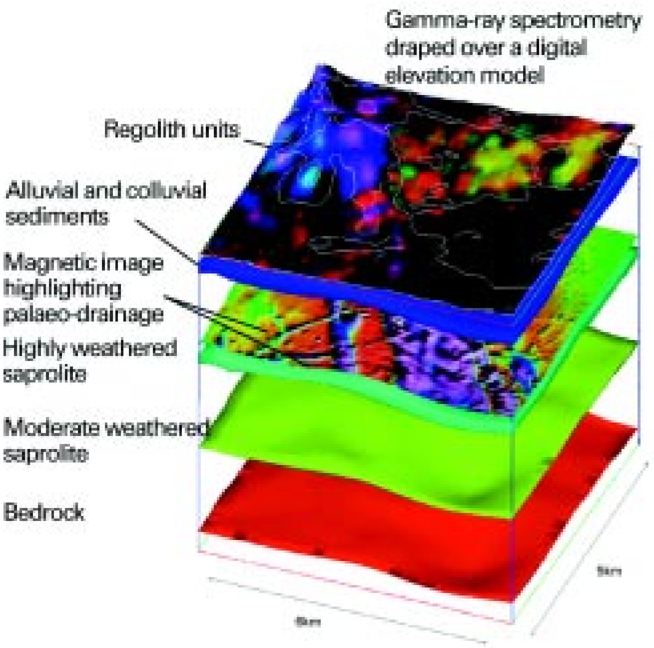

Fig. 20 A 3D block model displaying surface topography (DEM) and airborne gamma-ray spectrometry over regolith units in part of the Gilmore area. A magnetic image highlighting palaeochannels is floated between the transported and *in situ* contact.

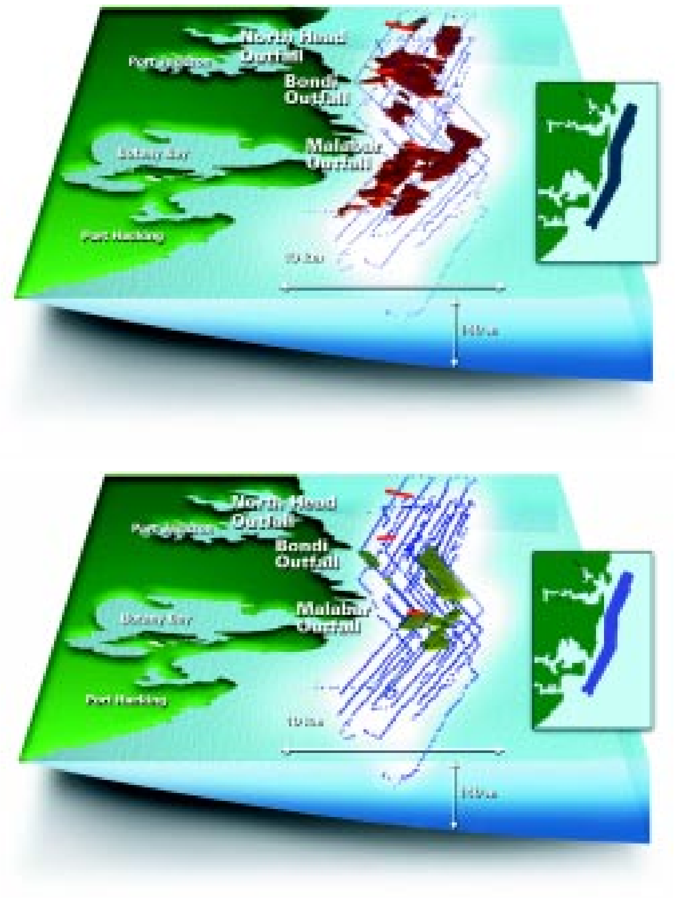

Fig. 21. Geochemical modelling of environmental oceanography data. (a, top) A 3D propane geochemical plume off Sydney. The plume has been clipped to show values greater than .25 ppm. (b, bottom) A 3D methane plume clipped to values above 12 ppm. The land is shown in green. Dots correspond to geochemical samples; red rectangles, ocean outfall sites.

3D visualisation

Scientific visualisation uses computer-generated imagery to facilitate an interpretation or investigation of scientific phenomena. For geoscientific applications, computer-graphic-visualisation tools provide an interactive environment whereby information from different sources is integrated and modelled in 3D. A range of 3D visualisation software packages is available; each has different levels of functionality, sophistication, and compatibility with commonly used 2D GIS platforms (e.g., ArcView, Arc/Info, and MapInfo).

Data processing

Data processing in visualisation and modelling software can be broadly divided into either data-flow or non-data-flow systems. Data-flow systems consist of modules that perform specific functions. These modules are linked together in a data processing pathway from the unprocessed datasets to the final enhanced display. Non-data-flow systems are more traditional in their architecture, and have either command-line or menu-driven operations.

The figures presented herein were generated from the data-flow 'Environmental visualisation system' (EVS), in which the user constructs a processing network of icons (selected from stored libraries) for performing the range of operations (e.g., gridding, filtering, subsampling). Networks provide an excellent pictorial representation (Fig. 17) of the data processing pathway, and enable the user to customise for specific applications. Once a network has generated a 3D object, various tools are available to rotate, shift, colour, resize, and illuminate it.

3D models and data uncertainty

Surface datasets are moderately easy to collect and analyse — viz., digital elevation models (DEMs), airphotos, and Landsat Thematic Mapper (TM) and gamma-ray spectrometric imagery, which provide continuous topographic, compositional, and geochemical information.

In contrast, subsurface information is generally localised (e.g., mines and borefields). It is generally restricted to points or profiles down a drillhole or to vertical slices (e.g., seismic profiles) and modelled imaged surfaces (e.g., depths to magnetic basement, or electromagnetic (EM) depth to weathered basement). For 3D subsurface volumetric models derived from drillhole datasets, statistical

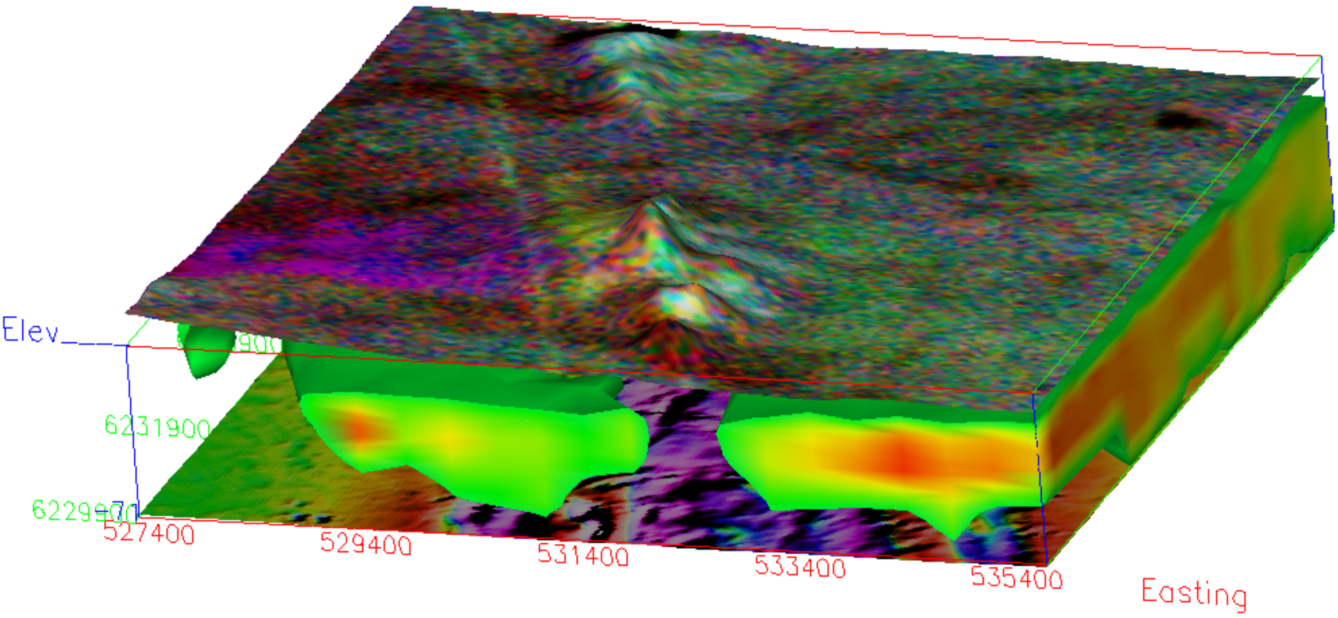

Fig. 22. A 3D block model displaying surface topography (DEM) and airborne gamma-ray spectrometric imagery over a conductivity plume derived from an airborne EM survey over the Gilmore area. An enhanced magnetic image at the bottom of the model provides a geological context. Areas of high conductivity (red hues) relate mainly to salt-bearing alluvial and colluvial sediments which have buried a palaeo-landscape with considerably more relief than the present day. The conductivity plume is clipped to show values greater than 500 mS/m.

interpolation techniques such as kriging create isosurfaces (3D surfaces of equal value) from scattered measurements (Fig. 18). The accuracy of such models depends on several factors — for example, drillhole sampling density and the level of interpretation built into the attributes being modelled. Widely spaced sample points will yield a more abstract, less accurate model than closely spaced sample observations. Such models can be generated from kriging either primary attributes (e.g., element concentration) or interpreted values or classes (e.g., transported or *in situ* zones within the regolith).

Building models based on interpreted attributes adds another source of potential error in the final image display. Inconsistencies in logging drillcore, for example, can be identified as random spikes in the 3D model (Fig. 18). Identifying errors highlights the use of 3D visualisation in checking data consistency and accuracy in databases. Similarly, assumptions built into simple geophysical models constructed to extract depth information from gravity, magnetic, and EM datasets are a potential source of error in the displayed image. Therefore, an understanding of the limitations of datasets being modelled, and the facility of representing any uncertainties in a display, are critical for assessing the accuracy and quality of the phenomena displayed.

Communicating with clients in 3D

Most geoscientific datasets are integrated and analysed in a GIS as thematic layers in 2D projections on paper or a computer screen. These themes are presented to clients as hard-copy outputs or as GIS datasets in either MapInfo- or ArcView-compatible formats. Communicating with clients in 3D is more of a challenge.

Displaying 3D information as static hard-copy products markedly degrades the information content and interactivity of the image being displayed. Preparing the information effectively for 3D visualisation requires the use of computer-generated depth clues — such as directed lighting, shading, and manipulation tools (e.g., resizing, rotating, etc.) — to create a dynamic 3D environment. Virtual reality takes the user–data interaction a step further by connecting and synchronising an image with the viewing direction of the user. This synchronicity is done by head-tracking display devices. Coupling the eye position with the image display provides a strong sense of reality and immersion or interconnectiveness between the user and the datasets being displayed. Despite active research in linking 3D GIS with a virtual-reality environment, the application of this technology to the wider community is still some way off. Currently 3D models are being provided to clients as:

- *Static image displays in standard image formats* (e.g., TIFF, MPEG, BMP).
- *Animated movie sequences*. Animations can be used to show temporal and non-temporal changes in spatial data. They effectively create dynamic displays by navigating through 2.5 (e.g., DEM image drape) or 3D models (e.g., fly-throughs, and migrating sections through 3D block models), and, for example, mapping hydrochemical pathways (water-table and solute fluctuations through time). They are presented to clients in either AVI or MPEG file formats, which can be readily viewed through PC multimedia players.
- *Virtual-reality modelling language (VRML) files*. Models saved as VRML files preserve the 3D integrity of an image, allowing the viewer to rotate, resize, and change illumination. VRML files can be viewed and manipulated via shareware Internet browsers and plug-ins. VRML files and animated movie sequences facilitate information dissemination to a wider client base (industry, general public, other scientists) and eliminate the dependence on specialised software to view and manipulate 3D objects.

Static images, animated files, and VRML files are also being incorporated as hotlinks with other spatially referenced maps and images in 2D GISs (ArcView). These linkages provide an important regional framework in which to interpret 3D models generated from district-scale datasets (e.g., mine-site and EM surveys).

Applications

The increasing importance of visualisation techniques for integrating and interpreting geoscientific information can be exemplified with reference to CRC LEME* regolith-focused studies in the Tanami (NT) and Gilmore areas (central NSW), and AGSO's modelling of environmental traces of sewerage discharge.

Regolith modelling

Understanding the regolith is important from an exploration perspective, because the surface expression of buried mineral deposits in highly weathered landscapes reflects its character and the physical and chemical dispersion processes that have operated in it. Regolith–landforms maps of the Tanami and Gilmore study areas are being complemented by 3D regolith and geochemical models over selected locations.

For Tanami, 3D regolith models derived from drillhole datasets incorporate gold geochemical plumes for visualising and resolving gold-dispersion trends from the mineralised host rock through the weathering profile to the surface (Fig. 19).

At Gilmore, surface mapping datasets (e.g., airphotos, airborne gamma-ray spectrometry, and DEM) provide only a partial understanding of regolith materials and associated geomorphic processes in a landscape buried by up to 70 m of Cainozoic alluvium and colluvium. Visualisation techniques integrating the surface datasets with subsurface (airborne magnetic, EM, water-bore, seismic profiling, and exploration drillhole) datasets (cf. Fig. 22) are elucidating the controls on metal and salt dispersion in the regolith and groundwater.

Chip and drillcore sample analysis distinguish regolith stratigraphy (e.g., sediments, saprolite, and saprock), mineralogy, geochemistry, and textures. Portable Infrared Mineral Analyser (PIMA) and downhole geophysical measurements (e.g., magnetic susceptibility and IP logs) reflect compositional, textural, and structural variations. These characters and properties are then modelled in 3D. Incorporating geochemical plumes in the 3D regolith models is helping to resolve metal dispersion from regolith-covered Au–Cu and epithermal Au deposits in the area.

Enhanced airborne magnetic data have effectively delineated palaeochannels containing maghemite pisoliths in the Gilmore area (Lawrie et al. 1999: AGSO Research Newsletter 30, 1–5). Integrating them with the 3D regolith models is helping to resolve the relationships between metal dispersion, palaeodrainage, and major structural trends (Fig. 20).

Regolith materials are an important source of soluble salt and control on salt mobility. Electrical conductivity maps derived from EM survey data can reveal areas of high salt concentration in the regolith. By incorporating conductivity and hydrogeochemical data in a 3D regolith framework, we can visualise the controls on salt distribution and movement in the landscape.

Sewerage-discharge traces

An environmental geochemical survey off Sydney in 1991 (Heggie et al. 1992: AGSO Research Newsletter 16, 23–24) recorded a suite of light hydrocarbons and temperature, salinity, and dissolved oxygen measurements at different depths in the water column. Methane, a unique tracer of sewerage discharges, characterised the hydrocarbons emanating from ocean outfalls.

Kriging of the geochemical data reveals the 3D geometry and locations of the anthropogenic hydrocarbon plumes (Fig. 21a, b). These hydrocarbon plumes are now being compared with 3D temperature and salinity models to better understand the controls on hydrocarbon dispersion.

Conclusions

The rapidly developing 3D visualisation technology is likely to play an increasingly important role in integrating, analysing, and resolving geoscientific information for constructing more robust exploration and environmental models. Visualisation techniques allow datasets from different disciplines (e.g., geomorphology, geochemistry, geophysics, hydrology, and spectral remote sensing) to be integrated, and

* The Cooperative Research Centre for Landscape Evolution & Mineral Exploration.

should encourage communication between staff in research teams.

The technology does have its limitations. Thus, the degree of extrapolation and abstraction of a model should be factored into the interpretation process. Again, sole reliance on the technology for interpretation can lead to an oversimplification of complex regolith and geological systems.

The use of 3D visualisation technology highlights the widening gap between hard-copy maps (2D) and interactive multimedia environments for communicating geoscientific information and concepts. However, visualisation and 3D modelling techniques are not an end-product themselves but a tool or process to solve a real problem.

[1] Minerals Division, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT 2601; tel. +61 2 6249 9455; fax +61 2 6249 9983; email john.wilford@agso.gov.au.