

New gOcad® developments in the field of 3-dimensional structural geophysics

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Abstract: For decades, geologists have tried to share 3-dimensional interpretations using 2-dimensional images (map, cross-sections,...). Use of block diagrams is also common but they are only made of three 2-dimensional slices, usually one horizontal and two vertical slices, but a full description of the volume is still missing. Block diagrams can even lead to misinterpretation since geologists tend to assume cylindrical structures to mentally relate structure traces on maps and cross-sections. In hard-rock geology, full 3-dimensional information (such as 3D seismic in the petroleum industry) is usually unavailable or spatially scarce. The starting point to any 3-dimensional modelling is very often a set of cross-sections and/or a set of points associated with information such as geological measurements (foliations, lineations, thickness of a unit, etc...). For the past century, geologists have been collecting such data. Using all available information still remains a big task since different kinds of data from different sources will not be consistent once put in a 3-dimensional space. Consequently, building 3-dimensional models involves a great deal of re-interpretation of the data. As such this is a great way to validate or refine previous interpretations which are often based on 2-dimensional representations and assuming consistency in the third dimension.

This paper deals with and advertises new developments implemented within the gOcad® software to enable the development of 3-dimensional structural geophysics models.

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Introduction

What is 3D modelling and why bother doing it?

For decades, geologists have tried to share 3-dimensional interpretations using 2-dimensional images (map, cross-sections,...). Use of block diagrams is also common but they are only made of three 2-dimensional slices, usually one horizontal and two vertical slices, but a full description of the volume is still missing. Block diagrams can even lead to misinterpretation since geologists tend to assume cylindrical structures to mentally relate structure traces on maps and cross-sections.

In hard-rock geology, full 3-dimensional information (such as 3D seismic in the petroleum industry) is usually unavailable or spatially scarce. The starting point to any 3-dimensional modelling is very often a set of cross-sections and/or a set of points associated with information such as geological measurements (foliations, lineations, thickness of a unit, etc...). For the past century, geologists have been collecting such data. Using all available information still remains a big task since different kinds of data from different sources will not be consistent once put in a 3-dimensional space. Consequently, building 3-dimensional models involves a great deal of re-interpretation of the data. As such this is a great way to validate or refine previous interpretations which are often based on 2-dimensional representations and assuming consistency in the third dimension.

In other words, 3-dimensional modelling provides the basis for:

1. visualisation of complex geological geometries,
2. refinement of previous interpretation by testing 2-dimensional interpretation against the third dimension
3. a framework for property modelling and test of the model against other datasets.

What is 3-dimensional structural geophysics ?

The research group at the Crustal Research Centre of Monash University (Melbourne, Australia) focuses on the tectonic evolution of highly mineralised or highly prospective terranes. These terranes usually have suffered a complex tectonic history and their constitutive rocks are poly-deformed and poly-metamorphosed. The methods involved are field based structural mapping, geophysical interpretation (potential field data and 2-dimensional seismic

transect) and geophysical modelling (inversion and 2-dimensional forward modelling). The scale varies from the plate tectonic scale to the mine scale.

These different data are integrated using 3-dimensional models and the models tested against potential field data (magnetics and gravity). The integration of structural and geophysical information to produce 3-dimensional geometrical and petrophysical models tested against geophysical datasets correspond to 3-dimensional structural geophysics.

At the Australian Crustal Research Centre of Monash University (Melbourne, Australia), we chose to use gOcad® (Mallet, 1992; ASGA, 1999) as our 3-dimensional modelling platform because it allows for realistic modelling of geological objects. This software also allows for an easy implementation of user-developed functions.

This paper deals with and advertises new developments implemented within the gOcad® software to enable the development of 3-dimensional structural geophysics models.

Input / Output of Data

Input data can be sourced from (1) GIS or other 3-dimensional modelling software which produce MIF (MapInfo Interchange Format) or DXF formatted files, (2) from spreadsheet software which produce ASCII files, column-formatted (each column corresponding to eg: location [X,Y,Z], structural measurements, grade, petrophysical properties such density and magnetic susceptibility, etc), and (3) from the interactive manual capture of structural information at one locality.

Input of GIS - DXF format

Figure 1 shows the dialog box allowing to import MapInfo Interchange Format files into gOcad and the resulting object in the gOcad camera. The input file corresponds to the MapInfo provided political boundary file of the world in the latitude-longitude coordinate system. The dialog box to import DXF formatted file is also shown.

Both converters will allow input for any point or line objects. The Mapinfo to gOcad® converter allows to import any numerical properties (floating point or integer values) previously assigned to MapInfo objects. Properties such as structural measurements (planar surfaces) are converted into a vectorial property which can then be used to constrain the geometry of a model (see Fig. 2).

Structural measurement can be entered using three different convention: (1) right hand rule (looking in the direction of the strike, the dip is on the right hand side, eg: 135 50), (2) dip / dip-direction (50 225, and (3) strike, dip, dip-direction (135 50 SW).

ASCII files input and interactive manual entry

These functions were specifically designed to allow an easy input of structural data (foliation and lineation measurements) from measurements taken in the field and digitally captured within a spreadsheet software.

Structural information is converted into a gOcad point (Fig. 2) associated to a vector property (normal to the measured plane and/or lineation) and any other numerical properties assigned to the points in the ASCII file. The structural points are used to constrain the model using normal gOcad® functions. Table 1 shows the ASCII file used to create the points in Figure 2.

Output of models

A common format used to exchange 3-dimensional models or objects is via the Virtual Reality Modelling Language (VRML). The gOcad® software already proposes to generate VRML models from a list of objects. Still under development, these filters do not allow to export a set of points which are color-coded according to a property. Since hard-rock geology data are very often sparse and discrete, it appeared necessary to be able to save clouds of points as VRML objects corresponding to (1) a stand alone VRML file or (2) a VRML object to be incorporated in a bigger VRML model by further file handling.

Figure 3 the dialog box allowing to output VRML sets of points. The generated VRML model is a spherical representation of the seismicity in the Banda Arc region and along the Australian / Indonesian subduction system. Political boundaries have been added using the classical gOcad function. Depth of hypocentres is color-coded.

Projections and associated toolbox

Projections

The scale to which modelling is undertaken varies from the global scale to the mine scale. Data are usually provided with a coordinate system ranging from latitude-longitude-elevation coordinates to mine grid coordinates; including the specific AMG system (Australian Map Grid).

Modelling of large scale areas (eg northern margin of the Australian plate) needs, for obvious reasons, to be performed on a spherical projection, but the ability to digitise boundaries of units, or structural elements in a map view or a cross-section view is still needed. New functions have been developed allowing to switch between the following projections (Fig. 4):

1. geodetic,
2. AMG,
3. homolographic (equal area sinusoidal),
4. spherical.

For each of these projections, elevation is still displayed and allows for a better visualisation in any of the projection system.

Toolbox

In the case the seismicity in the Banda Arc region, building an envelope surface bounding the hypocentres required the development of a new function allowing (1) to slice a complex set of points in smaller sets, and (2) represent the selected points in a 2-dimensional space (Fig. 5). Digitisation of a bounding line for each of the slices was performed using common gOcad® tools. The bounding surface was consequently built by linking together each of the lines.

Slicing the set of points is done according to a user-defined value (\pm tolerance) of a user-defined property assigned to the points (eg longitude). Points falling within the interval [property-tolerance, property+tolerance] are consequently represented in a new space where the slices can be represented as a cross-sections. In figure 5, the new space is defined by X = latitude, Y = longitude and Z = elevation (or depth).

3-Dimensional Structural Geophysics

Three dimensional geometries are often derived from two dimensional data such as surface mapping, interpretative cross-sections and kinematic interpretation of micro-to mesoscopic structures. To provide further constraints during 3-dimensional modelling, forward geophysical modelling capabilities have been built in gOcad® using Noddy (Jessell and Valenta, 1996).

Noddy

Noddy is a 3-dimensional forward modelling package enabling computation of potential field data for 3-dimensional geometries. It has been developed by Dr Mark Jessell at Monash University. The software works from a set of kinematic events that defines a history applied on an initial layer-cake stratigraphy. The software computes the resulting 3-dimensional geometry using space-filling equations on a 3-dimensional regular and cubic grid which the exact analog of a gOcad's voxet. Once the 3-dimensional geometry is created, gravimetric and magnetic fields are calculated using interactively set values for density and magnetic susceptibility.

From a 3-dimensional gOcad surface model to a Noddy geological block model

Once a surface model is created in gOcad®, the cells of the voxet (3-dimensional regular grid) are divided into sets (or gOcad's regions) according to their relative position with respect to the volumes bounded by the initial surfaces. In other words, all the cells falling within the same volume bounded by a set of surfaces belong to the region defined by these surfaces. In Fig. 6a, the green unit was defined by (1) its lithologic boundaries (with the blue and light-brown units) and (2) the thrust on the left hand side separating the dark-grey unit from the above lithologic package.

From a Noddy geophysical block model to a geophysical response

Once the gOcad voxet is divided into regions, properties such as density and magnetic susceptibility are assigned to each of the regions. This is done either by assigning a constant value throughout a whole region or using the geostatistical tools built-in gOcad. The newly created geophysical

model is exported to Noddy and the geophysical response is calculated running Noddy in batch mode. The calculated result is consequently re-imported into gOcad as a 2-dimensional raster (Fig. 7). This link shows the full process from surfaces to a potential field response.

Other Functions

A full set of functions allowing a complete two-way exchange of data/models between Noddy and gOcad® has been developed (Fig. 8). These functions allow the user to:

- (1) export a gOcad voxet model as a Noddy Geological Block (Fig. 6),
- (2) export a gOcad voxet model as a Noddy Geophysical Block (Fig. 9),
- (3) compute the geophysical response of a model previously exported (3),
- (4) load the raster images corresponding to a model,
- (5) import a Noddy Geological Block as a gOcad voxet,
- (6) perform a calculation of the geophysical response of a voxet model and load its raster images (Fig. 7).

Conclusion

These new developments make gOcad® more hard-rock geology friendly.

1. They allow for an easier input of data into the software, importing files from commonly used GIS software.
2. They allow to test a 3-dimensional model against geophysical datasets,
3. Associated with Noddy, gOcad® has been added a geophysical forward modelling capability,
4. They allow the modelling to be carried out over large areas where spherical projection is absolutely needed.

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