Structural secrets

Structural geology techniques can assist in mineral exploration and resource development. Clare Bond, Dave Hutchinson and John Grocott of Midland Vally Exploration, Glasgow, UK, explain

Natural resources are big business. In February 2008, 14 natural resource extraction companies were listed on the London Stock Exchange's FTSE 100. Some of these majors have interests in both petroleum and mineral resources, which are often run as distinct businesses. While this may make sense economically, it minimises the opportunities for knowledge, and cross-application transfer of technologies. Midland Valley Exploration, based in Glasgow, UK, is breaking this barrier by applying structural geology experience and techniques across the mining and petroleum sectors.

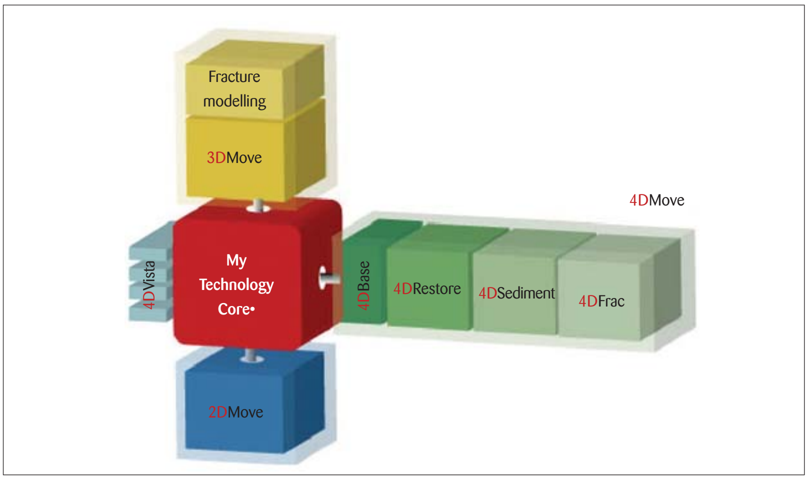
Driven by the need for increased recoveries while operating within tighter cost and environmental envelopes, structural restoration and validation should form an integral part of the data analysis workflow. Validation and structural analysis of geological models is a front line tool for identifying uncertainty. It provides the basis to model 'unseen' components of the structure, or deposit, and the controlling elements of a resource system.

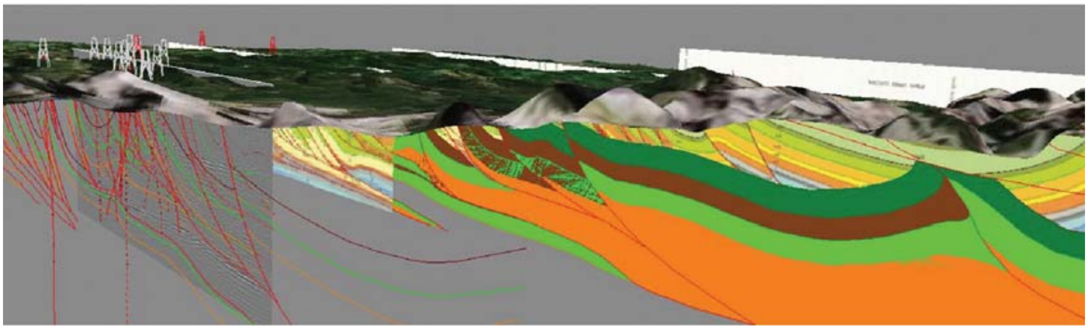
Resource development

Structural restoration and validation of 2D and 3D models allows the prediction of palaeo-surface geometries, fault architecture and fluid migration pathways, through geological time. Validation of present day static mine models in 2D and 3D can optimise pit and mine design, and drill hole placement, as well as provide an input for fracture modelling. The latter can be used to improve understanding of ground conditions (such as for planning block cave projects or for in-pit slope stability studies). Typical mining orientated software packages, such as Vulcan and MineSite, output static models that can be imported into Midland Valley's software. Structural validation yields cross-sections and 3D models that are geometrically and geologically valid, both at the present day and throughout their evolution (see image below). The starting point is to use a structural model to link deposit-scale observations to their regional and semi-regional context.

Achieving structural coherence across relevant time and spatial scales is the key to effective exploration programs and resource evaluation. With this in place, structural modelling at the mine-scale can lead to increased ore body knowledge and a reduction in geological uncertainty.

Structural restoration allows 2D and 3D to be tested for validity





Right: Geo-referenced integrated data set, including field and well data, digital elevation model (DEM) and cross-sections (data from GeoBase (DEM), the Department of Natural Resources, Canada (cross-sections), Husky Structural Data Set from the Canadian Foothills, 1995 (seismic) and Google Earth (drape).

Below left: Discrete fracture network model created in 3DMove shows the spacing and orientation of fracture sets. In this example there are two fracture sets. Set one (blue) ~ 26,000 fractures, fracture set two (cyan) ~ 24,000 (approximately 20% of calculated fractures are visualised). Data courtesy of PECOH.

Below right: The shape of the hanging wall may be used to predict fault geometry and depth to detachment. Different modelled scenarios can be compared to show possible variations and uncertainties, and the information used to aid pit and mine design

The Move software uses a data hub management system in which maps, cross-sections, dip and drill hole data are fully geo-referenced (see image above). Geological maps can be draped over high resolution digital elevation models (DEM) using 4DBase. While the surface construction tools in 3DMove allow models to be built from the integrated data, which can provide information on the geometry and extent of potential ore bodies, to improve the focus of exploration drilling programmes.

Placing 2D data in a 3D context provides insights into the linkages of structural and intrusive components. Combining 3D-visualisation with evolution through time, 4D animations can be produced that show the structural evolution of a region, from initial deposition, through geological history to the present day geometry. This leads to an increased understanding of terrane evolution and highlights issues in a mine model.

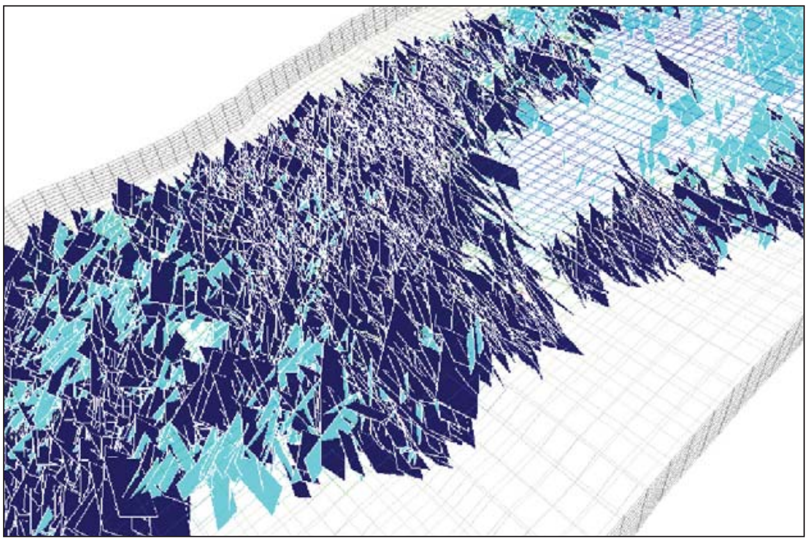
Fracture modelling

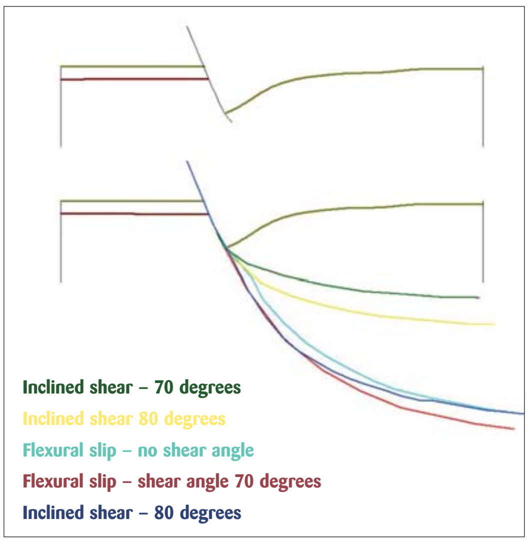
Three dimensional models can be restored and then forward-modelled to capture attributes including strain and surface curvature. For fracture modelling, these attributes are used as inputs to build a discrete fracture network (DFN), which can be further refined with additional field and/or drill hole data. Discrete fracture networks built in this way, particularly in areas with sparse data, are complementary to deterministic fracture models which rely on the statistical extrapolation of data from drill holes. Comparing fracture models based on these different approaches can help reduce uncertainty. Fracture models can be used for geo-technical analysis and to predict mine hydrological conditions and fluid flow anisotropy at the time of mineralisation, and allow the prediction of faults and other structures not identified in drilling (see image below left).

Application

Techniques such as block caving are becoming more common in a drive to minimise the impact of resource extraction on the natural environment, and to target ore bodies that would otherwise be uneconomic. Discrete fracture network modelling can be used to model rock-mass characteristics, which can assist in the prediction of rock behaviour. This type of information is critical for the planning of block-cave projects and the planning of open pit operations, as well as more traditionalmining methods.

The software has dedicated algorithms to predict fault geometries for different deformation mechanisms based on the shape of the rocks in the hanging wall. By varying the deformation mechanism, several scenarios of fault shape and depth to detachment can be modelled and compared (see image below right). For open pit





operations and underground workings, this can be an important tool to predict fault locations within the mine region, which have an important bearing on local *in-situ* rock mass strength and stability.

Increasingly, modelling of multiple scenarios is being used for risk assessment and uncertainty analysis. The types of scenarios tested range from different model starting points to the impact of deformation mechanisms on fault geometries (as in the image left). Models can also be tested against known data, for example by drilling virtual-holes into the model and comparing to real life data.

It should be recognised that more than one model may be geologically valid. Knowing the areas of greatest model uncertainty can be a key tool for resource development, planning, and extraction. Uncertainty analysis allows decision makers to determine whether different, valid, structural scenarios lead to variations in the geological outcome. A geological model is always just a model, so understanding the controlling factors that impact decision and outcome can provide significant commercial advantage, whatever the resource.

Further information

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