Unconstrained vs Geologically Constrained Inversion Modelling

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Since the mid-1990's despite the rapid advances in technology and understanding of mineral systems the rate discovery for world class deposits has continued to decline (Figure 1) (Schodd, 2012). The decline in exploration success and changing economics, particularly in mature mineral camps has led to the development of deposits at greater depths in both new discoveries and extensions to operating mines.

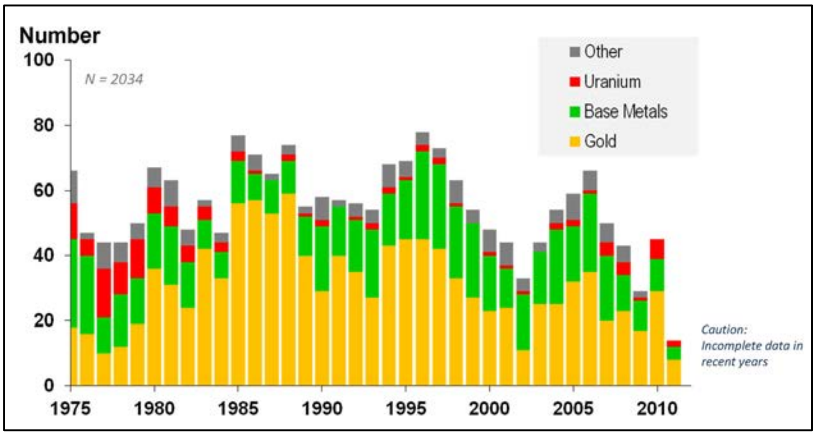

Figure 1: Number of deposits found each year – by commodity (1975-2011)

Source: MinEx Consulting September 2012

Modern mineral exploration uses a variety of techniques to evaluate the potential mineral deposit often including detailed geophysics which is now routinely modelled in 3D using an unconstrained inversion. This type of modelling relies on the geophysical properties without taking into account the geological either from interpretation or drilling information. The lack of geological control can make these models difficult to interpret and as a result they poorly represent the observed geology. However, with advances in inversion technology combined with specialist software and simplified workflows, it is becoming easier to integrate geophysical and geological knowledge into consistent geological models.

Constrained geophysical inversion modelling is a quantitative method which allows the inclusion of observed geology and interpretation to reduce uncertainty by honouring the geophysical response while preserving geological identity. This ultimately results in more robust geological models which can be used not only for exploration, but also for resource definition and mine planning.

Geological modelling

With increasing computation power and with improved software, geological modelling is becoming routine part of exploration and mineral resource estimation. 3D geological models have largely replaced map and cross-section interpretation in early exploration and have allowed more sophisticated geological models for resource estimation, geotechnical studies and mining. Modern geological modelling software allows the integration and reconciliation of diverse range of datasets, ensuring consistency and allowing analysis.

The purpose of a geological model changes as the project matures. For instance in exploration a geological model is important for targeting and drill planning, where analysis on limited geological understanding can be the difference between making major discovery or walking away from a project. In mining a geological model is equally important, as it not only provides a basis for resource estimation, but also underpins geotechnical and mining planning.

Whilst 3D modelling is a powerful tool, modelling results are limited to the data and data quality available but also most importantly the uncertainty in that data. Detailed potential field data is often collected within the exploration phase, but is commonly ignored in mining as the drilling density increases. However, by incorporating this data using 3D constrained inversion process into the 3D modelling workflow can greatly enhance confidence in the geological model, particularly where drill hole data is more limited. This can assist with both planning of exploration and resource definition drill programs as well as in long term mine planning.

Unconstrained inversion

Unconstrained inversion modelling is relatively common practice in mineral exploration. Although the unconstrained inversion method may be applied on many different geophysical data sets this paper focuses on potential field data (magnetic/gravity). Magnetic and gravity surveys are often completed over mineral prospects during the exploration phase and are generally of high resolution. The process of unconstrained inversion of potential field datasets can be a powerful method to aid interpretation by helping develop understandings the 3D architecture of the subsurface, such as identifying large structures, geological boundaries or alteration systems. The aim of the inversion modelling process is determine the distribution of physical rock properties within the earth's crust that could provide a best fit result to the measured response of the survey area.

Unconstrained inversions require potential field data, topography and a 3D mesh. The principle process of an unconstrained inversion is to modify the physical rock properties within each cell of the mesh to reduce the misfit between the observed response data (at surface) and the computed response created from the 3D mesh (Figure 2). After several iterations, one plausible solution or model that corresponds to the observed geophysical signature.

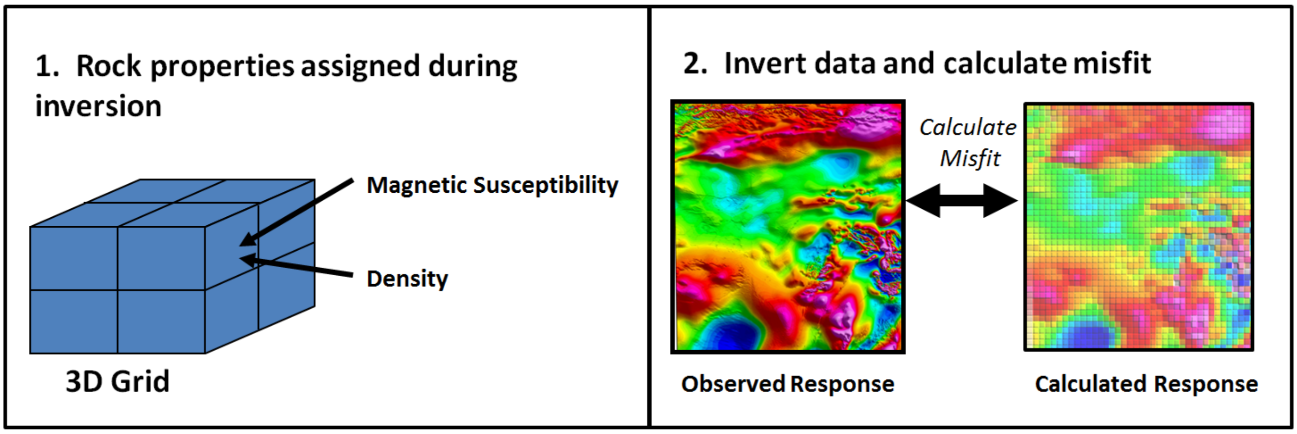

Figure 2: Generalised unconstrained inversion workflow

There are several advantages to unconstrained geophysical inversions including they require no geological information and are not biased by preconceived ideas on geology and they are quick to produce. Allowing many models can be generated and tested to provide a best fit to the input data even where there is little existing geological information. Inversions results provide a geologist with an idea about what are possible geometries based on the geophysical response. From such models different geological hypothesis can be tested in the subsurface beyond known extents.

Results from an unconstrained inversion are not directly constrained by geology, so this can create ambiguity which ultimately makes interpretation of the resulting model difficult. Additionally the non-uniqueness of the results increases the uncertainty, where a number of plausible solutions exist.

Constrained inversion

Unlike unconstrained inversions, the geologically constrained inversion provides an integral link between geophysics and geology. It is capable of honouring the geophysical response while preserving unique geological identity. This is achieved through using geological model coupled with rock property information that provides the link between the geophysical response and the subsurface geology.

The constrained inversion process requires a geological starting model rasterized into a 3D mesh, petrophysical rock property data (magnetic susceptibility/density) for each modelled unit, topography and geophysical data (magnetics/gravity) (Figure 3). The 3D mesh has physical rock properties unique to each geological unit and a geological property (litho-type) assigned to each unit. The principal aim of a geologically constrained inversion is to modify the cell properties in accordance with a chosen algorithm (Figure 4). For example; only physical rock properties may be changed during the inversion, or geological units (geometries) may be modified during the inversion, or alternatively both can be modified to achieve a best fit model.

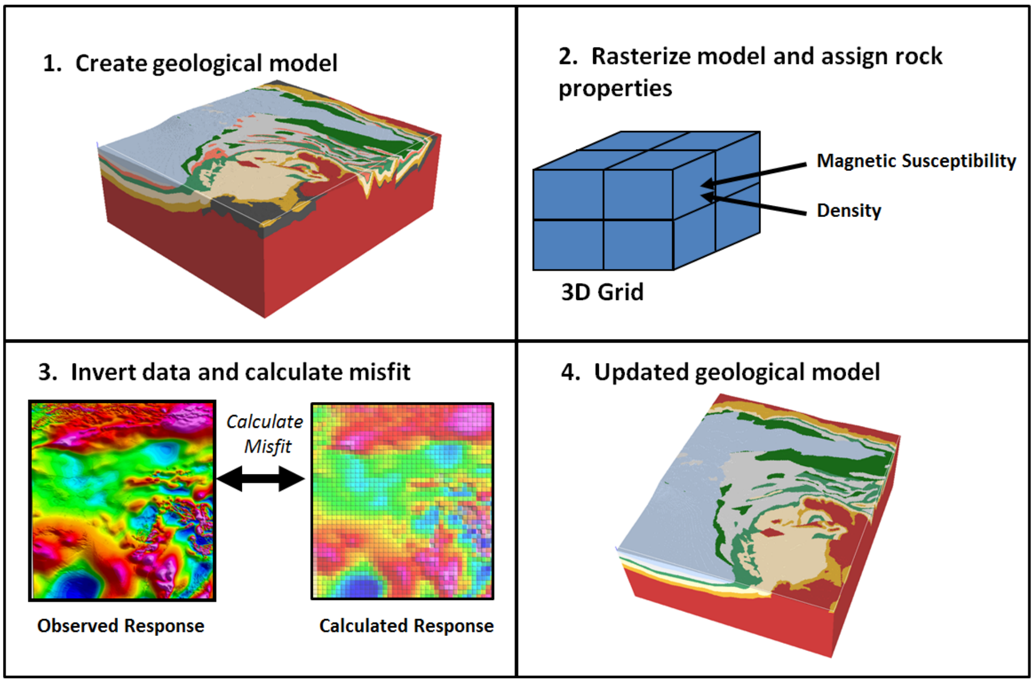

Figure 3: Generalised workflow of the constrained inversion process

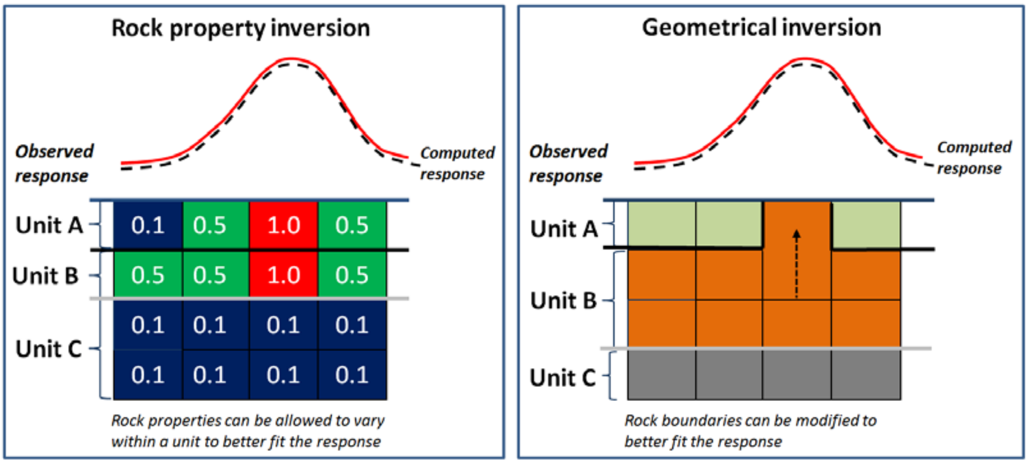

Figure 4: Schematic representation of the inversion process

The aim of this process is to reduce the misfit between the observed and computed geophysical dataset while still honouring the geology datasets. Inversions still remain non-unique solutions however the additional geological constraint provides greater certainty in final results. After several iterations, a plausible model that best satisfies both the geological and geophysical information is kept.
The number of plausible solutions remains extremely large but the solution is capable of validating the geological model, or highlighting key areas of uncertainty where additional data or revised interpretations may be required. This method additional enables several geological hypotheses to be tested.

Conclusion

Improved 3D geological modelling technology allows for better analysis of large multidisciplinary datasets. Increasingly 3D modelling techniques are being used to review data across all development stages, from exploration, resource development and mining. Robust geological models that integrate and honour all datasets are required in order to provide a basis from which to make critical decisions about the project. Incorporating geophysical inversion techniques provides a way of improving confidence without having to increase the density of drilling. Ultimately through this it is possible to reduce the uncertainty and risk in exploration and resource development while minimising expenditure.

References

Schodde, R. 2012. Global Mineral Exploration Trends. MinEx. China Mining Conference 3 November, 2012.