The Integration of Geological and Potential-Field Data Sets

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The two most widespread data sets available for the interpretation of regional geology are potential-field measurements and published geological maps. Given the non-uniqueness of the interpretation of potential-field data, and the general sparseness of geological data in a three-dimensional context, the integration of these two types of data provides one of the best opportunities for improving our ability to produce three-dimensional maps of the geology of the crust. The methodologies for performing this integration are still in their infancy, and this paper will provide an overview of some of the approaches that we have taken to resolve this difficult problem.

We can think of two end-member approaches to the integration problem, essentially geological and essentially geophysical approaches. In both cases the results can be useful, but are also limited.

In the geological approach we try to produce three-dimensional maps of the geology, using widely available geological CAD packages, based on observed data, and interpreted cross-sections. This model can then be used as the basis for potential-field calculations, and the discrepancies between the observed and modelled field strengths used as a basis for modification of the geological model. While in principle this is a logical approach, and certainly one that is comfortable for a geologist, the difficulty lies in determining how to properly adjust adjust the geological model so as to preserve the geological integrity while at the same time improving the fit to the geophysical data.

In a geophysical approach we can attempt an inversion of the potential-field data to produce a model of the distribution of densities or magnetic susceptibilities, and can constrain the outcome using rock property values at known locations. Many of the current schemes apply a smoothness criterion in order to constrain the results. While this can be useful when applied to mine-scale geology, where continuous gradients in rock properties associated with mineralisation do occur, on a regional scale the most common observation is that of relative uniformity of rock properties within lithologically controlled boundaries, with sharp gradients between lithologies, although again alteration can modify this pattern locally.

In this poster we will present the results of an approach at an integrated geological and potential-field modelling scheme (known as "Noddy"), and look at some of its strengths and weaknesses when used for both forward and inverse modelling.

The starting point for modeling is an initial stratigraphy, which not only specifies the relative positions and thicknesses of lithological units but also defines geophysical rock property information such as density, magnetic susceptibility (including anisotropic susceptibility), and remanent magnetisation. This initial stratigraphy may be uniform and layer-cake, or derived from a pre-existing voxel or triangulated-surface data set.

The structural modeling is based on a kinematic description of deformation. Thus we do not consider the forces involved in deformation, but instead use the displacement equations for a given deformation, and consider also the relative timing of these events. Each deformation event is described in terms of four classes of parameters. These parameters may be entered directly into the model or extracted from other data sources when available.

Once a three-dimensional geological model has been defined, it is converted into a voxel (volume element) model, and the field strengths are calculated either by applying an algorithm based on Hjelt's (1972, 1974) equations to solve for dipping prisms or by using a Fourier-domain technique. For this calculation we make the assumption that the rock properties are uniform within one cube, but they need not be so within a lithological unit.

As the geological models are time-based, complex rock property behaviour can be investigated. Alteration haloes around igneous intrusions and faults can be defined by assuming that, at the time of formation of the structure, the alteration profile is a function of distance from the causative structure. We may likewise incorporate dynamic variation of both remanence and anisotropy, as the rocks deform. These quantities are assumed to behave as Cartesian vectors and tensors, respectively. Initial orientations are assigned uniformly within each rock type, but are subsequently tracked individually for each voxel.

This approach provides the ability to rapidly test different ideas for the three-dimensional structure responsible for a given potential-field anomaly, and by making the modelling follow geological rules, we remove the problem that the model, though it may fit the potential-field data, is geologically implausible. Nevertheless there remains a significant drawback to this type of modelling: it is still quite hard to simultaneously produce good fits to both geological and geophysical data, and it may require many iterations of the modelling process to reproduce the observed data.

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We have extended the forward modelling use of Noddy by developing a two-stage inversion scheme, which first of all searches a geological history parameter space using genetic algorithms, and then modifies the output from this model using a Monte Carlo routine to modify the location of lithological boundaries. We will present the results of this inversion scheme as applied to simple and complex synthetic data.

In summary we have attempted a number of approaches to the problem of integration of geological and potential-field data, and, as with many such problems, find that the different approaches may all be appropriately applied to different geological settings. Perhaps the question is not so much whether a particular technique is applicable, but when each technique should be applied.