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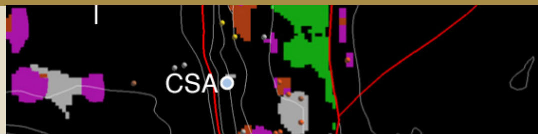
Mapping the footprint of ore deposits in 3D using geophysical data

Potential field data provides alteration signatures



Richard Chopping and Simon van der Wielen

Geologists identify rocks mainly through identifying the minerals they contain. These might include the minerals which make up the majority of rocks we see at the Earth's surface, such as quartz or feldspars. They could also be minerals which are more commonly associated with ore deposits, such as pyrite (fool's gold), pyrrhotite or magnetite. Geologists identify these minerals by their unique properties such as hardness, colour, crystal form and cleavage, streak, how heavy the mineral is, or how magnetic it is. The latter two properties are termed 'physical properties', namely density and magnetic susceptibility.

"This link between mineralogy, physical properties and geophysical responses is the key to mapping the signatures of ore deposits using geophysics."

Recent developments in technology allow for the mapping of the distribution of physical properties derived from geophysical data in 3D. These developments, which utilise geophysical inversions of gravity and magnetic data (Williams et al 2009), have produced 3D models of density and magnetic susceptibility. In a project conducted between 2006 and 2008 for the Predictive Mineral Discovery Co-operative Research Centre (***pmd****CRC*), the authors examined the 3D signatures of ore deposits in the Cobar region of New South Wales (NSW; figure 1).

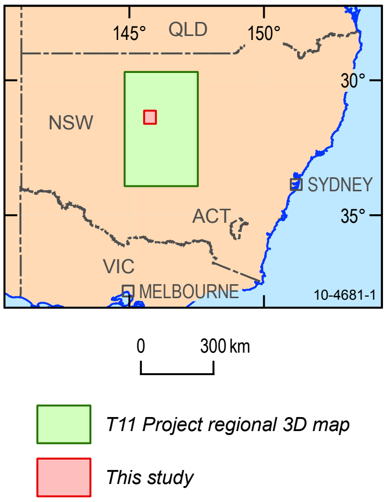


Figure 1. Location of the study area used for alteration mapping and the study area for the ***pmd****CRC* Cobar Project T11 in the Lachlan Subprovince and Cobar Basin.

Linking geology and geophysical data

The physical properties of geological materials are the link between geology and geophysics. A high density area of the Earth will produce a gravity high; a low density area will produce a gravity low. Likewise, an area with high magnetic susceptibility will produce a magnetic high. These geophysical responses are linked to the minerals contained within the rocks in those areas; an area of rock which contains more dense minerals has a higher density and will thus produce a gravity high. This link between mineralogy, physical properties and geophysical responses is the key to mapping the signatures of ore deposits using geophysics. Often the processes which form a mineral deposit will produce minerals which have vastly different physical properties to the minerals already formed in the host rocks. These differing physical properties resulting from the processes of mineralisation can produce a geophysical response.

The study area

The Cobar region has a rich mining history spanning more than 100 years (Glen 1987). The area has mainly been mined for copper, gold, silver, lead and zinc, at mines such as CSA, Great Cobar and Peak. Significantly for this study, geophysical responses due to mineralisation are known in the Cobar region. Studies of these responses have focussed predominantly on the magnetic and gravity responses, although there are also anomalies in other geophysical data (such as electromagnetic data). The focus of this study was to map the alteration mineralogy in 3D utilising geophysical techniques.

Chemical alteration in 3D

To understand the method by which the changes resulting from the formation of ore deposits (termed chemical alteration) can be mapped in 3D requires some elaboration of the concept.

Chemical alteration is defined here as the change in the original (termed primary) mineralogy of a rock that results from fluids and/or heat from the mineralising system interacting with the rocks through which they pass. The physical properties of rocks that host ore deposits are controlled, predominantly, by the mineralogy of the rock (Carmichael 1989). Consequently alteration minerals which have properties that differ by a considerable amount to the primary minerals in a rock will produce a rock which has properties which differ from the original rock hosting the alteration.

However, it should be noted that chemical alteration does not result in a completely altered rock. Many rocks remain a mixture of primary and alteration minerals. As an example, a rock may contain 40 per cent primary minerals and 60 per cent alteration minerals. In this case, the density of the rock will be 40 per cent of the density of the primary minerals and 60 per cent of the density of the alteration minerals. For magnetic susceptibility, the relationship is more complex, but many authors suggest that it can be assumed to be linear for concentrations of magnetite less than 20 per cent (Carmichael 1989).

Because of variations in mineralogy and other factors, any host rock in a mineral system will not have a single, definitive set of physical properties. When plotted on a graph of physical properties, the variability in properties of a host rock can be defined by a limited field (shaded polygon; figure 2). This limited field implies that rocks altered to an assemblage of alteration minerals will be contained by a field which converges around the physical properties of that assemblage. This is a feature we term the 'alteration cone'

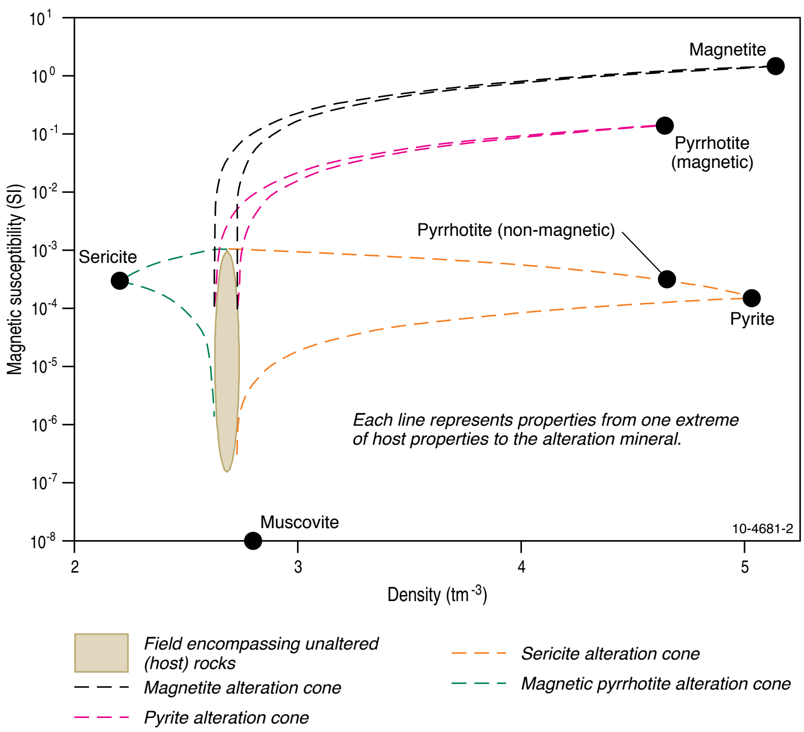


Figure 2. Magnetic susceptibility versus density plot showing a hypothetical location for a distribution of host rock properties and the location of some alteration minerals. The dashed lines indicate paths that progressively altered samples will take on this scatter plot. Any samples that plot within the field defined by these dashed lines (the 'alteration cone') can be inferred to be altered to the property shown at the apex of the alteration cone.

(Chopping 2007; figure 2). Samples plotting outside the field of expected properties for a given host lithology, but within an alteration cone, are inferred to be altered to the alteration product which is located at the apex of the alteration cone.

3D inversion of geophysical data

The concept of the alteration cone can be used to interpret the results of potential field 3D inversions. The gravity and magnetic inversion programs—GRAV3D and MAG3D—used for this study were developed by The University of British Columbia-Geophysical Inversion Facility. The programs produced volumes of density contrast and magnetic susceptibility. These contrast with a background (reference) density or magnetic susceptibility which can be converted to an absolute density or magnetic susceptibility by adding the reference density or magnetic susceptibility for that cell. For this study an area 40 kilometres east-west, 50 kilometres north-south and 16 kilometres deep was constructed, and this model was divided into cubic cells of side length 250 metres. The density and magnetic susceptibility for each of these cells was derived using GRAV3D and MAG3D and the geological lithology for each cell was obtained from a 3D geological map constructed for the Cobar region (van der Wielen and Korsch 2007). The property distribution for each individual lithology, which was derived from the potential field inversions, can be queried for signatures of alteration by applying the alteration cone methodology discussed above.

Queries for alteration to magnetite, pyrrhotite, pyrite (potentially non-magnetic pyrrhotite) and sericite were undertaken. These are the simplest alteration assemblages that can explain the physical property trends observed in the inversion results. These are not the only alteration types anticipated in the Cobar region, but these alteration minerals have the most significant density and magnetic susceptibility contrasts when compared to the host rocks. They are also likely to occur in sufficient quantities within the inversion cells to be detected by the inversions. Some previous studies in the region indicate that there may be alteration zones up to 30 metres wide containing 80 per cent sulphides; this would correspond to one or two per cent sulphides in a cell of 250 cubic metres.

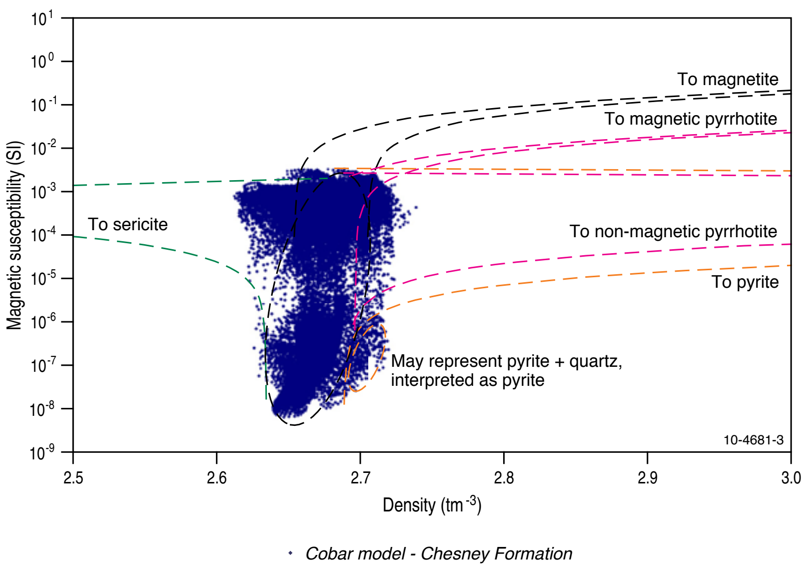


Figure 3. Magnetic susceptibility versus density plot for each cell of the Chesney Formation. Properties are derived from a 3D potential field inversion of magnetic and gravity data in the Cobar region.

Changes in alteration types

A good illustration of the use of this technique is the Chesney Formation. This formation hosts a significant quantity of base metals in the region (Cook et al 1996). Its physical properties, derived from the potential field inversions, show a fairly typical trend, with the majority of cells clustered together (figure 3). The alteration cones encompass almost all of the samples that appear to be anomalous in their inverted properties. Some samples appear to show densities and magnetic susceptibilities that would be more akin to alteration to pyrite and quartz, however, these are interpreted to be pyrite in the final results to remain in our

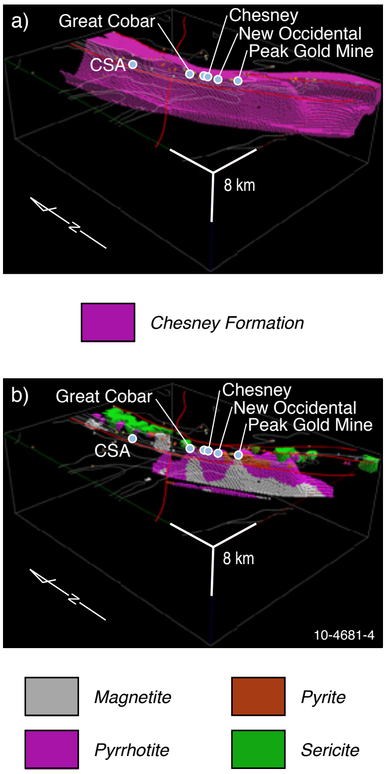


Figure 4. a) 3D distribution of the Chesney Formation; b) distribution of cells according to alteration type which was obtained by querying the 3D model for all cells of the Chesney Formation with properties interpreted from the alteration cones (figure 3).

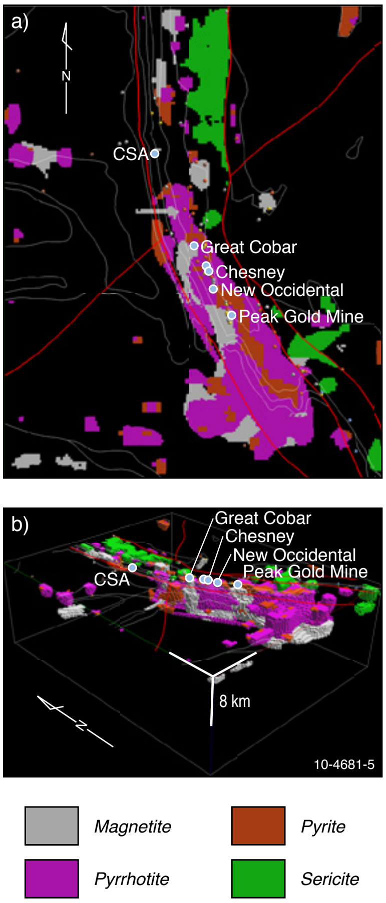


Figure 5. 3D distribution of alteration for all lithologies in the Cobar region, viewed from a) above and b) the same perspective as for figure 4. Areas shown in black indicate that the geological units show normal host rock physical properties.

simple alteration classification (figure 3). The results, when viewed in their true 3D context, show that there appears to be magnetite pipes, representing zones of more oxidised alteration, cutting into pyrrhotite or pyrite, which may represent zones of more reduced alteration (figure 4).

When viewing the alteration results for all lithologies in the study region (figure 5), it is apparent that the major deposits of the region lie within the changes between alteration types. These changes are either from magnetite-dominant alteration to pyrrhotite-dominant alteration or from pyrrhotite-dominant alteration to pyrite-dominant alteration. The overall pattern of magnetite, pyrrhotite and pyrite-dominant alteration zones is consistent with previous alteration studies in the region (Cook et al 1996; Lawrie and Hinman 1998; Stegman 2001).

The location of the known deposits in the Cobar region, located on the change from one alteration type to another, was entirely expected based on our knowledge of the mineral systems operating in the Cobar region. The change in alteration type corresponds to the conditions that promote maximum deposition of base metals (Cook et al 1996; van der Wielen and Korsch 2007). The change from magnetite-dominant to pyrrhotite-dominant reflects a change in the redox state. The change from pyrrhotite-dominant to pyrite-dominant may also represent a change in the redox state, a change in the availability of iron (Shi 1992), or possibly a temperature effect if the pyrite-dominant alteration actually represents non-magnetic pyrrhotite-dominant alteration. Pyrite and non-magnetic pyrrhotite cannot be distinguished on their densities and magnetic susceptibilities alone, as these properties are virtually identical for both minerals. A higher temperature allows the non-magnetic hexagonal crystal symmetry form of pyrrhotite to be stable, whereas, at a lower temperature, the magnetic monoclinic crystal symmetry form of pyrrhotite is stable (Dekkers 1989).

Conclusions

This technique has allowed us to attribute anomalies in physical properties, with respect to the 'normal' host properties, with an expected alteration type. The technique is particularly applicable in the Cobar region because there is limited physical property contrast between host units and alteration is the predominant cause of geophysical anomalies. The technique is also applicable in regions that are under significant cover. As with any geophysical technique, the exact results will depend on the property contrast from host to altered product. A strong host-to-host property contrast will require a more detailed geological model to obtain the best results, but mapping of gross alteration trends should still be possible with only a very simple inversion reference model.

Acknowledgements

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The authors

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