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Minerals geophysics

Terry Harvey
Associate Editor for Minerals geophysics
terry.v.harvey@glencore.com.au

Geophysical inversions – finding a Volkswagen in a cubic mile of rock

In the early days of mineral exploration geophysics the emphasis was pretty much limited to finding anomalies. Geophysical techniques were in their infancy, instrumentation was often quite crude, and the supporting mathematical theory was relatively basic. There just wasn't the measuring precision, nor the mathematical tools and the processing hardware.

Geophysical instrumentation dramatically improved with the advent of semiconductors and digital recording. Similarly, geophysical processing advanced with improved mathematical techniques and the ability to efficiently process the much larger amounts of data that was afforded by ongoing increases in computing power.

These improvements advanced the scope of mineral exploration geophysics beyond basic anomaly finding. Improved mathematical capabilities (both software and hardware) led to better geophysical modelling. Visual matching of these models to more accurate field results led to estimations of the dimensions and properties of source bodies. With more sophisticated data processing and presentation capabilities, systematic mapping of rock types distinguished by pertinent physical property contrasts also became possible.

Once we had the means to accurately model the geophysical response from a physical property distribution, and the necessary computing power, we had the tools to undertake geophysical inversion. This is the iterative process combining theoretical modelling and comparison with field results to recover a model of the causative physical property distribution. As mathematical tools and computing capacity further advanced, inversion capability improved. Inversion progressed from 1D (e.g. early SIROEX GRENDL layered earth inversions) to 2D (e.g. early ZONGE DOS resistivity and IP geo-electric section inversions), to the 3D inversion tools (e.g. UBC potential field 3D model inversions) in routine use today. We now have capacity to recover an estimation of the 3D distribution of the physical property that generated the anomaly pattern in the first place.

Inversions changed the way we interpreted geophysics, and made geophysics more accessible to other geo-scientists, nowhere more so than in electrical geophysics. Compare the IP pseudosection and the resulting inversion in Figure 1. I know which one I'd rather show the exploration manager as a drill target!

But inversion goes beyond this. Hand-in-hand with developments in inversion tools came the means to manipulate the controls within the inversion process. Basic inversions typically generate a smooth model, which isn't necessarily replicating the sharp boundaries we often see in geology. The ability to sharpen up boundaries, and alter horizontal and vertical sensitivities in response to the geological setting were early variations. However, some care was needed. I had a presentation that caused consternation within the exploration team. I called it 'dial-a-depth', and it illustrated the dramatic changes in the apparent depth of burial of a modelled IP-anomalous target that could be induced merely by changing the vertical settings of a 2D IP-resistivity inversion.

With improved user interfaces, this quite simplistic manipulation of the inversion process advanced to the much more elaborate and specific limitations imposed in a constrained inversion. In this process, an inversion is forced to fit physical boundary conditions and property ranges derived from a known or pre-conceived geological model. In its simplest form, this could simply be restricting an inversion to, say, having the modelled source body lie beneath a known depth of cover. In its full form, a constrained inversion must fit within a very detailed 3D model. But a word of caution – given the wide range of possible solutions, particularly with potential field inversions, the final model may appear to fit the pre-conceived geology but this is no guarantee of the model's validity. The resulting inversion may be more of what you want, rather than what's really down there.

In a further advance, co-inversion using two or more geophysical techniques offers even more control and constitutes another powerful tool. However, the assumption that there are sympathetic variations in different physical properties isn't always right – magnetic properties may distinguish two different rock types, but density or electrical property contrasts may be elsewhere. Like any subjective process, it should be applied with careful thought.

Despite all these advances in instrumentation and mathematical processes we don't yet have sufficiently powerful and sensitive geophysical techniques, nor the appropriate inversion processes, to detect and characterise a Volkswagen buried within a cubic mile of rock as has been claimed, but we've come a long way from geophysics' basic beginnings. And the advances continue.

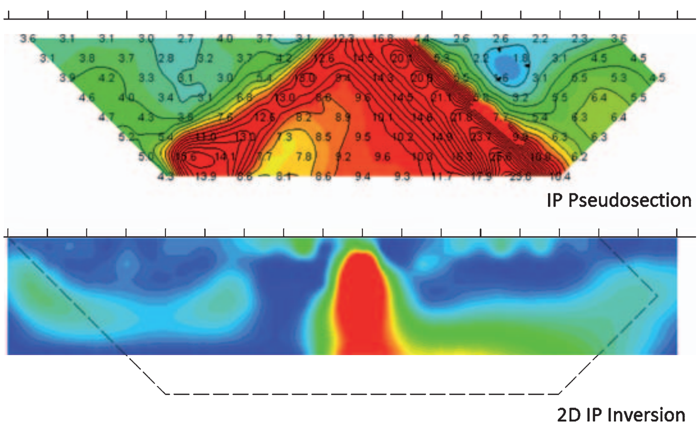

Figure 1. *IP Pseudosection and 2D IP Inversion.*