Improving resource density models via surface gravity inversion

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SUMMARY

Density is one of the fundamental physical properties required in a mining operation, underpinning the calculation of ore tonnages and thus metal produced. The resource density model captures this information, but is often based on a relatively sparse collection of density measurements. Gravity data are a direct reflection of the true distribution of subsurface density, and can be used to improve the resource model. The example of the Ravensthorpe nickel laterite mine illustrates the improvement in the resource density model that results from combining high resolution surface gravity with the set of borehole logged density readings.

Key words: resource density model, constrained gravity inversion, reconciliation

INTRODUCTION

A resource density model is fundamental to a mining operation because it is used to predict ore tonnages milled and, ultimately, metal produced. Uncertainty and error in a resource density model may have as big an impact on reconciliation of predicted versus actual production as uncertainty and error in the corresponding ore grade model. In spite of this, density measurements are most often not collected in anywhere near the same quantity as, for example, assay data. The set of density measurements may be sparse in both spatial coverage and per lithology or other pertinent domain in the resource model. Furthermore, QAQC on density measurements is not beholden to the same rigour as is placed on geochemical assays in accredited laboratories.

Surface gravity data collected over a mineral resource represent a direct reflection of subsurface density variations. If the signal due to the rock volume of the resource can be isolated, the gravity data can be used to improve a resource model otherwise based only on borehole or core density readings. A constrained gravity inversion is an intelligent interpolator between borehole density readings. For a domain-based resource model that uses density statistics to populate material domains (e.g., lithology blocks), the inverted gravity data constrain the geometrical variations of the domains or their assigned densities.

The Ravensthorpe nickel laterite deposits in Western Australia represent the ideal case for using surface gravity to improve the resource density models. The range of material types encompasses variations of 0.8 g/cc, and the deposits are hosted from surface to 40 m depth, so the gravity data can be used at their maximum resolution.

GEOLOGY AND DATA

Contrasting material types drive the mining operation at Ravensthorpe. In the simplest breakdown, an upper layer of limonite must be mined separately to a lower layer of saprolite, and each layer is sent to a separate processing stream. Furthermore, a variably present indurated caprock at the surface represents waste and must be stripped. The interface between all layers is extremely variable (Figure 1) and requires grade control drilling on 10 x 12.5 m spacing in order to sufficiently characterise its geometry. Mixing of the limonite and saprolite materials causes processing problems and mining is therefore a precision operation. To this date, reconciliation of tonnes mined and processed has been difficult, and attention is focussed on the resource density model that underlies all downstream calculations.

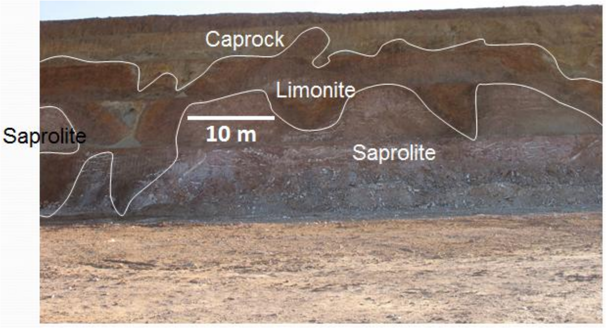

Figure 1. Photograph of pit wall showing complexity of main material interfaces. Note 10 m scale bar, which represents grade control drill spacing.

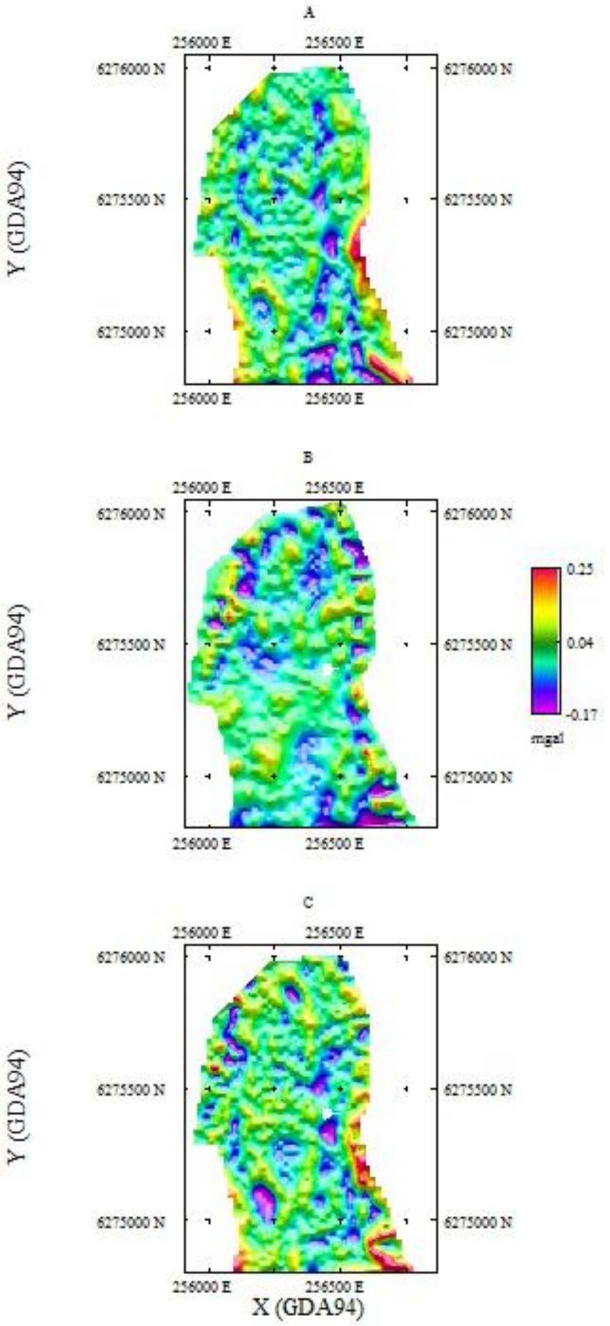

Figure 2. Comparison between (A) measured gravity and (B) theoretical gravity response of initial resource density model, both high pass filtered at a 200 m wavelength. (C) Difference between field data (A) and theoretical gravity (B). All images share a common colour scale.

A large dataset of borehole density readings has been collected at Ravensthorpe. These have a good spatial and lithological (material domain) distribution, but unstable hole conditions lead to blowouts and collapse, and require QAQC measures to filter what readings can be used. These densities have been statistically assigned to material types and the original resource density model was constructed by populating material blocks with associated densities, rather than relying on directly kriging borehole density values. Material types and interfaces are well characterised by multi-element geochemistry and a geological block model represents a sound starting point.

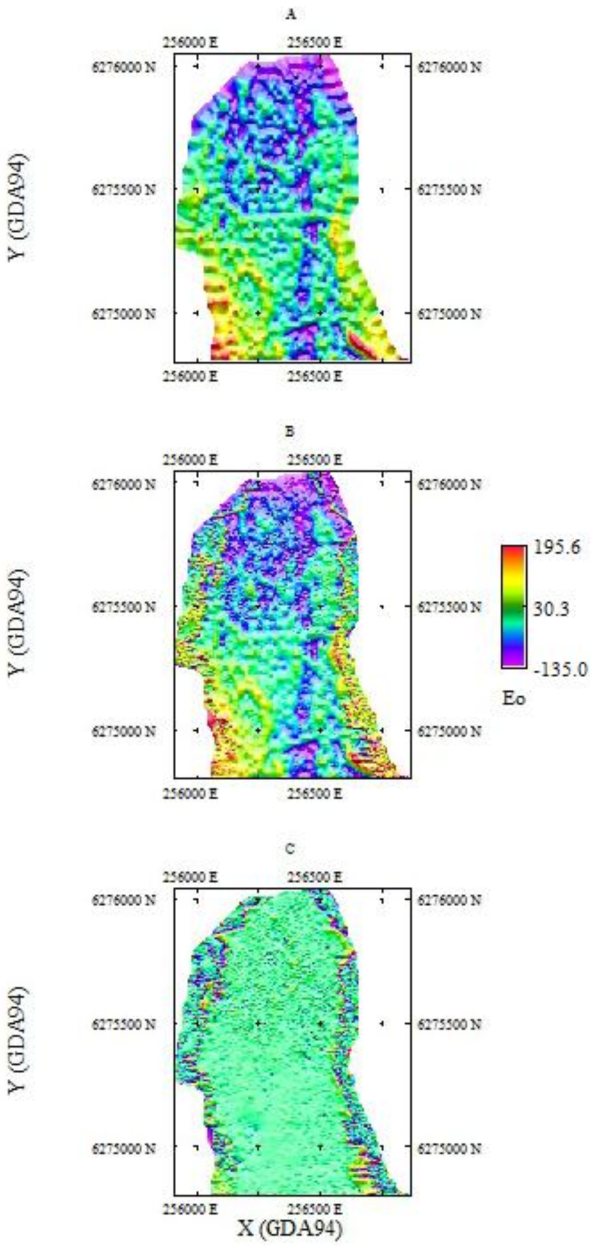

Figure 3. Comparison between vertical gradient of (A) measured gravity and (B) theoretical response of final resource density model. (C) Difference between field data (A) and theoretical response (B). All images share a common colour scale.

In order to contribute information on the scale required for resource modelling, surface gravity data were collected at 20 x 20 m station spacing across some of the resource areas. High standards of data collection were demanded for such close station spacing, including frequent repeats and precise positional accuracy to less than +/- 5 cm in both horizontal and vertical directions. Stacking was performed for 40 s per station and 120 s at the base station.

RESULTS AND DISCUSSION

Despite confidence in the position of drilled material interfaces in the resource model, and the large database of logged densities to assign to material types, the theoretical gravity response of the original resource density model shows immediate discrepancies with the measured gravity data. Figure 2 compares this theoretical response with the measured field data over the same area, after performing a 200 m wavelength high-pass filter to isolate near-surface signal. Some features appear in common but numerous areas exhibit quite different gravity anomaly values. Figure 2C contains the difference between forward-modelled and measured gravity, illustrating that the differences can be of equal amplitude to the original responses. The result suggests that density variations are not sufficiently modelled within otherwise well constrained material boundaries. This derives from the fact that densities were statistically assigned to the resource model based on lithology and not on the real spatial distribution of logged density.

After inversion of the gravity data using the material interfaces of the resource model as constraints at the drill holes, the new density distribution honours both the geological boundaries and the surface gravity signal (Figure 3). Comparing the vertical gradient of field and forward modelling, it is apparent that details of the density variation have been well captured, and the difference grid in Figure 3C shows very close correspondence except at the edges of the survey area. The inversion was carried out in three stages: inversion of the Bouguer corrected data to allow heterogeneity in the basement, followed by inversion of the vertical gradient for the near-surface regolith layers, and then inversion of the Bouguer data for another few iterations in the basement.

In an endorsement of the statistical distribution of density values originally assigned to lithologies, the density ranges per material type after inversion remain very similar (Table 1). The exception is in the lowermost layer of saprock. This generally sits below the mineralised zone and has benefited from relatively little drilling. Drilling is stopped by a combination of entering saprock and falling below a threshold nickel value. In this layer of limited sampling, the gravity data may provide comparatively more constraint to the results. As a general extension to this, the improvement brought by the gravity data to a resource model is magnified in areas of wider drill spacing prior to the grade control stage.

Regolith Material	***Density range (g/cc)***	
	Resource model	***Inverted model***
Caprock	1.47 – 2.15	1.25 – 2.1
Limonite	1.28 – 1.98	1.2 – 2.05
Saprolite	1.21 – 2.06	1.2 – 2.2
Saprock	1.71 – 2.1	1.3 – 2.2

Table 1. Comparison of the original range of density values per regolith material with the range post-inversion of the surface gravity data. The ranges are very equivalent with the exception of lower inverted densities in the saprock.

The high-resolution gravity surveying also has immediate qualitative value before inversion. It is capable of helping predict limonite troughs and saprolite highs (Figure 4). In this

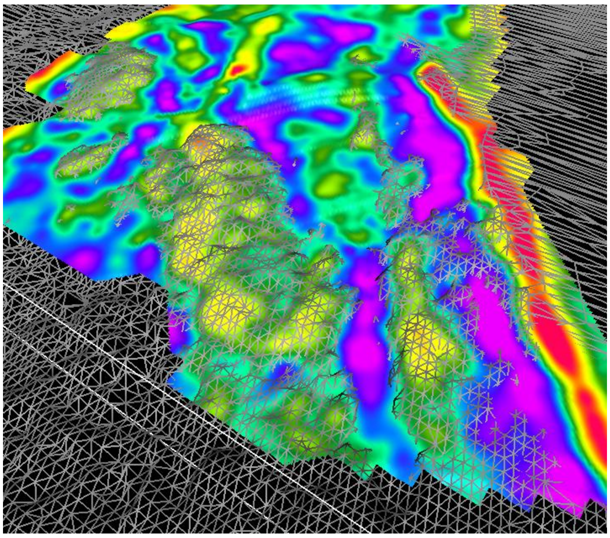

Figure 4. Perspective view over the Halley's North resource, showing 200 m residual Bouguer gravity and the wireframe of base of limonite. There is good correspondence between saprolite highs in the wireframe and high gravity (yellow/red), or limonite troughs and low gravity (blue/purple).

capacity, the gravity map becomes a predictor of different materials destined for different processing streams. Especially prior to dense grade control, it is critical to understand the relative abundance of the two main material types in order to plan steady mill feed for each stream. The sparser the drilling, the greater is the value of this predictive interpolation capability to mine planning and drill programs.

CONCLUSIONS

Most mining operations lack sufficient density measurements to characterise the orebody being exploited. An inaccurate resource density model leads to reconciliation problems between ore mined and metal produced. Surface gravity data can be used to improve a resource density model by inverting the data while still respecting elements of the resource model. Constrained inversion of the gravity data at Ravensthorpe respects the geological interfaces determined by visual and geochemical logging, while recalculating a more realistic density distribution within each of these domains. The impact of adding gravity data varies directly with the resolution of the survey and inversely with the depth of the deposit. The high resolution survey over the surficial Ravensthorpe nickel laterite deposit represents the ideal case to maximise the contribution of surface gravity data.

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