Laterite resource definition through geophysics

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SUMMARY

The Ravensthorpe nickel laterite deposits in Western Australia are defined by different regolith layers that must be mined and processed separately. A surface caprock layer is waste material (and used as road base), beneath which are limonite and saprolite layers that are sent to separate processing streams. As the regolith grades into saprock below this, the mineral resource falls below an economic level. Within the limonite and saprolite, further variations in material properties affect processing results, including during the beneficiation, or physical upgrading stage. The boundaries between these layers are geometrically complicated, such that very close-spaced drilling would be required to define them to an accuracy relevant to mining. In an effort to mitigate wider drillhole spacing, different geophysical techniques have been trialled to trace boundaries between drill holes. Any technique must be rapid, with high spatial resolution, and preferably continuous, in order to cover the many kilometres of resource drilling and eventually be deployed in a mine pit during operation. Petrophysical logging serves as both a check on the surface geophysics and a potential avenue for predicting material behaviour where multi-element geochemical assays alone have failed. Conductivity and gamma logging, for example, characterise discrete zones that are not represented in the geochemistry or visual logging. Active and passive seismic, electromagnetics, and ground-penetrating radar show variable success in mapping different interfaces. Ground EM demonstrates the most promise, mapping both resistive caprock and a conductive, clay-rich, upper limonite layer that is also indicated by the petrophysical logging.

Key words: nickel laterite, resource modelling, near-surface geophysics, petrophysics.

INTRODUCTION

The variability within regolith layers of the Ravensthorpe nickel laterite deposits, both in terms of interface geometry and material properties, requires close-spaced holes to define the resource through drilling alone. Figure 1 demonstrates some of the extreme spatial variation that can occur, and the inability to capture sufficient detail of this geometrical complexity with holes spaced 20 m apart, or sometimes 40 m. In particular, the limonite and saprolite material must be mined and processed separately, so the mine requires mapping techniques that can accurately trace this interface between drill holes.

In an effort to improve the accuracy of resource modelling, a number of shallow geophysical techniques have been trialled at Ravensthorpe. Methods include single station passive seismic, ground penetrating radar, and time-domain electromagnetics. Complementing the surface geophysics, numerous campaigns of downhole petrophysical logging have collected density, natural gamma, inductive conductivity, and magnetic susceptibility.

Figure 1. Photograph of pit wall showing complexity of main material interfaces (left). Note 20 m scale bar that represents current grade control drill spacing. Pre-existing structures control localised, deep weathering, illustrated by the abrupt limonite features traced by the dashed white line (right).

The two goals of applied geophysics at Ravensthorpe are (1) improved geometrical definition of material interfaces in the pursuit of more accurate resource models, and (2) definition of material properties to better predict behaviour during the beneficiation process, a physical ore upgrading process that precedes metallurgical recovery in the mill.

Because porosity, carbonate, silica, and clay content all vary between material types, hopes are pinned on electromagnetic methods like GPR and EM to provide rapid mapping capabilities.

Figure 2. Location of Ravensthorpe deposits (from Google Maps).

GEOLOGICAL MODEL

The Ravensthorpe deposits are located close to the town of Ravensthorpe on the south coast of Western Australia (Figure 2). Nickel enrichment is a result of weathering processes in the Bandalup ultramafic suite of the Archaean Ravensthorpe Greenstone Belt. The nickel is concentrated in limonite and saprolite layers in the regolith profile (Figure 3), and these two layers have sufficiently different physical and chemical properties that they must be mined separately and sent to different processing streams. As the regolith grades into fresher saprock below saprolite, the mineral resource falls below an economic level. The surface layers of unconsolidated sand over lateritic duricrust (caprock), which are variably present, are unmineralised. For logging purposes, the regolith is divided vertically into caprock, limonite, saprolite, and saprock/fresh rock. Within this are zones of greater clay content, including localised areas high in smectite that cause issues downstream. Mapping the geometrical complexity of material interfaces is key to accurate mine planning, and characterising and predicting the behaviour of materials during the beneficiation process will lead to better nickel recovery.

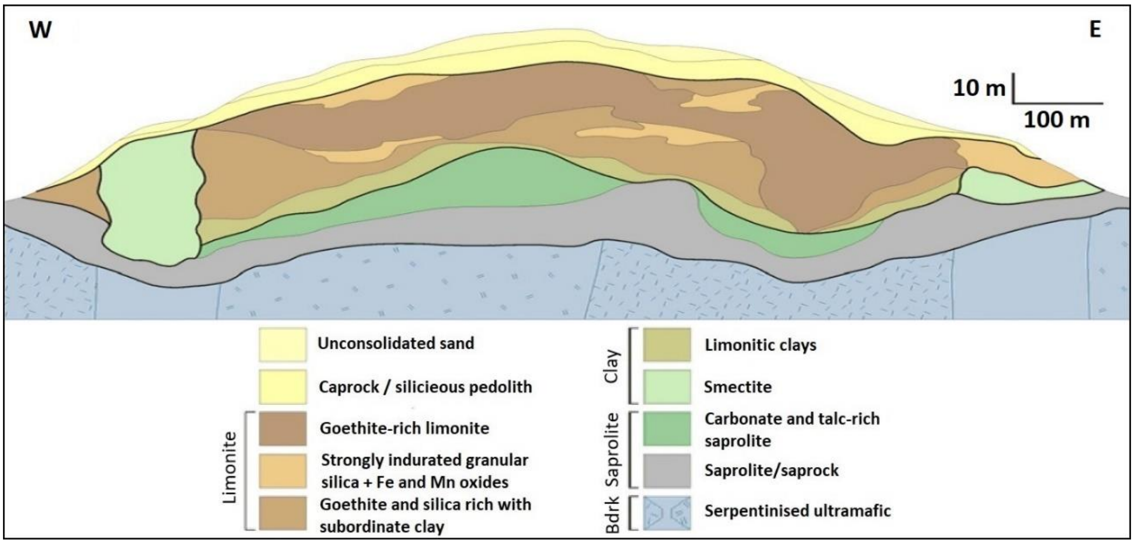

Figure 3. Schematic cross section of regolith layers, adapted from BHP (2003). Limonite, clay, and saprolite contain economic nickel mineralisation. Note ~5x vertical exaggeration.

METHODS AND RESULTS

Early airborne EM results using the shallow mapping capabilities of the SkyTEM system (Reid et al., 2010) suggested a gross difference between more conductive limonite versus resistive saprolite. Because the spatial resolution of the AEM was insufficient for resource modelling, this has led to trials of high-resolution ground electromagnetic techniques. In tandem with these trials, the collection of petrophysical data is informing expectations of mapping capabilities. Data collected to date do not support clear relationships between petrophysical properties and geologically logged regolith materials or material subgroups. Results from inductive conductivity logged using a 40 kHz Century 9512 probe (Figure 4) illustrate the relative uniformity of conductivity between different material types, aside from the expected higher conductivity of the clay-rich materials. This suggests that mapping a limonite-saprolite interface will be difficult via electromagnetic methods. Figure 4 shows that even within the material types of limonite and saprolite, many subgroups (with variations in e.g., clay or carbonate content) will not be distinguishable through conductivity. However, it is clear from downhole profiles, such as in Figure 5, that there are discrete conductive zones that correlate across drill holes. These transgress different material types and subgroups. Given the poor performance of multi-element geochemical assays alone in predicting beneficiation behaviour, the petrophysical observations are leading to an investigation of physical properties combined with geochemical properties in developing beneficiation predictions.

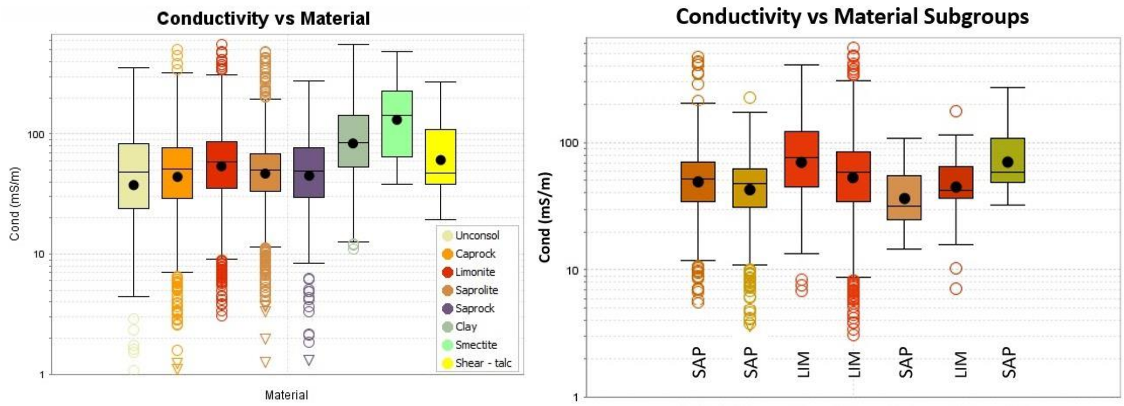

Figure 4. (Left) Inductive conductivity for eight different regolith materials shows little discrimination outside of clays. (Right) Even within the saprolite (SAP) and limonite (LIM) regolith materials, there is limited variation across different subgroups. The higher conductivity saprolite on the right-hand side is highly serpentinised. The highest conductivity limonite lithology is goethite-rich.

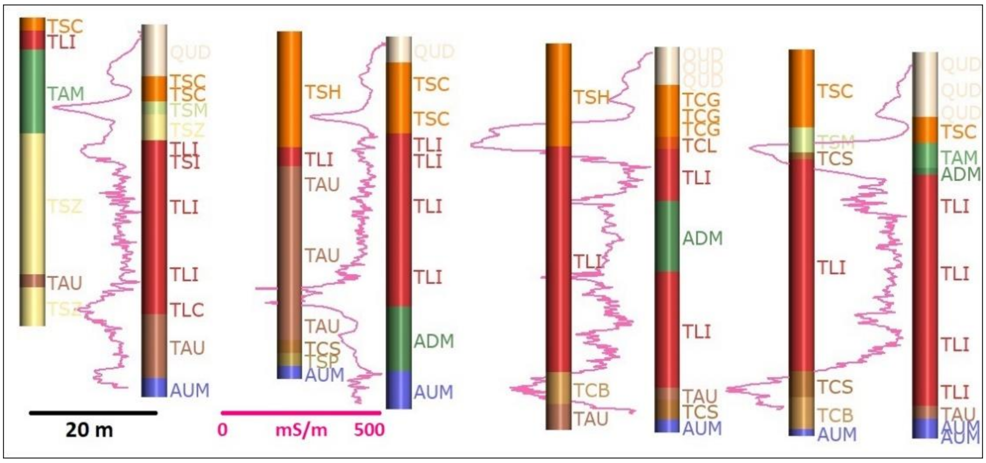

Figure 5. Downhole inductive conductivity logs (pink profiles) show variations that correlate across holes but do not have any consistent material or material subgroup association. Rock codes reflect material subgroups, where caprock is TSC and TSH (orange), limonite is TLI and TLC (red), saprolite is TAU, TCB, and TCS (browns), and saprock is AUM (purple). Mafic dykes appear in green as TAM, and the talc-rich shear zone (TSZ) on the left is yellow.

GPR is a very rapid and high-resolution technique, limited usually by depth penetration. This makes it unlikely to be able to map the limonite to saprolite boundary in the range of 10 to 30 m depth. Figure 6 shows a typical GPR amplitude section using a low-frequency 21 MHz system, using a velocity of 0.1 m/ns to convert travel time to depth. The base of high reflectivity usually corresponds with the base of caprock at up to 10 m below surface. However, signal attenuation with depth may also be influencing this apparent result.

Single station passive seismic data modelled using the horizontal to vertical spectral ratio (HVSR) method (Nakamura, 2000) appear to map the transition from saprolite to saprock, which represents the base of economic mineralisation, and therefore the maximum depth of the resource. However, the variability in shear wave velocity along a regolith profile, whether due to material or geometric variations, may not allow this technique to be used away from drill hole control with sufficient resolution for mining, in the absence of prior shear wave velocity information. Because the drilled resource sits entirely above the water table, no sonic logging has been possible. Dry-hole, vertical seismic profiles are required to establish the true shear wave boundaries in the subsurface.

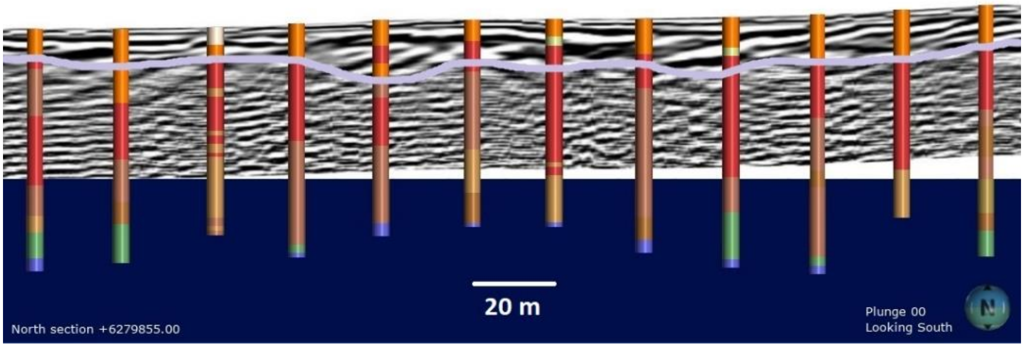

Figure 6. The base of high GPR reflectivity (light purple line) usually corresponds to base of caprock (orange lithology), equivalent to top of limonite (reddish brown).

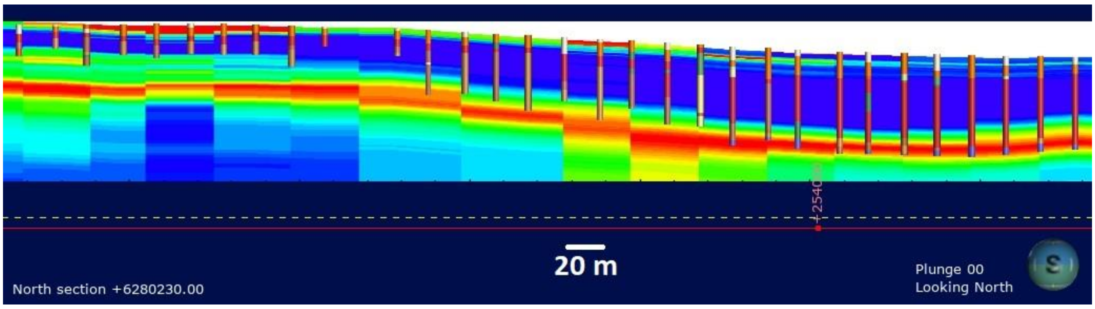

Figure 7. Passive seismic results are best modelled via HVSR as mapping the transition to saprock. The peak amplitudes, normalised for each sounding and appearing red, follow saprock intersections at the bottom of holes in the east (right-hand side) and suggest that drilling was far too shallow to reach saprock in the west.

Given the initial airborne EM encouragement, ground EM was trialled using the Loupe TEM system (Street et al., 2018) to map different regolith layers. Inversions of these data consistently map a resistive caprock layer that correlates very well with drillhole interpretation, as well as laterally continuous, conductive zones that occur mostly in what is logged as upper limonite, and which match the downhole inductive conductivity logging. An example is indicated on Figure 8. The occasional more clay-rich nature of the upper limonite has previously been noted during logging. The extents of these zones correlate to first order with Al distribution (Soares 2021), which, within the limited number of elements assayed for, is most representative of clays, montmorillonite being the largest contributor to the conductivity.

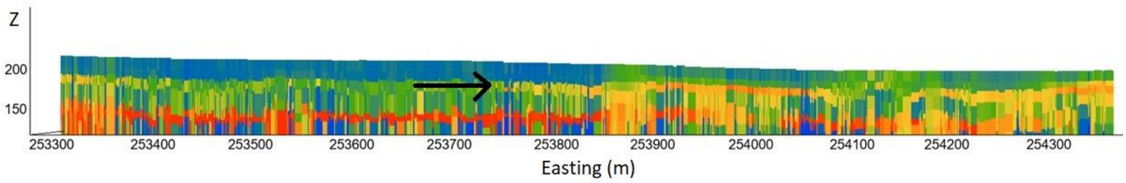

Figure 8. Inverted ground TEM conductivity from Soares (2021) maps the top resistive caprock layer as well as the thin and semicontinuous conductive zone in the upper limonite, indicated by the black arrow, which is picked up by petrophysical logging. The lower conductive horizon reflects noise in the data and anything at this depth is not interpreted.

CONCLUSIONS

High-resolution subsurface mapping is required across the Ravensthorpe nickel laterite deposits to mitigate the effects of insufficiently close drill spacing on resource modelling. Single station passive seismic soundings appear to trace the boundary between saprolite and saprock, but lateral inconsistency in seismic velocities may preclude this method being used away from drillhole control. Variable silica, carbonate, and clay content between and within regolith layers has led to trials of rapid electromagnetic methods such as GPR and ground EM for mapping interfaces, with particular focus on the boundary between limonite and saprolite. However, a large database of downhole petrophysics indicates there is no simple correlation between physical properties like conductivity and logged geology. Ground EM appears to be the most promising tool at Ravensthorpe, mapping both the resistive caprock thickness and the upper limonite conductive zones that correlate with higher clay content. These zones of anomalous conductivity, as well as natural gamma, transgress logged geological units and suggest an avenue for new characterisation of material properties via petrophysics as well as geochemistry.

ACKNOWLEDGMENTS

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