Integration of Disparate Data Types for Resource Estimation – A Nickel Laterite Example

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ABSTRACT

Modern technology and the need for published results have created the tendency for exploration to concentrate on drilling and assaying rather than building a broader geological understanding. Though grade is vitally important to a resource estimate, density and volume are also very important aspects that require equal consideration.

Wet tropical nickel laterites are developed in humid environments over ultramafic bedrock where the nickel and cobalt are enriched to economic levels by weathering, leaching and supergene processes. These laterites often occur over rugged terrain at higher elevations where there is sufficient rain and stability for the long lateritisation process to occur. For nickel laterite profiles, the variable terrain and significant material type changes within the relatively thin profile make density and particularly volume estimation, just as significant as grade in resource estimation and assessment of resource risk.

Drilling alone is generally not a cost-effective way to reduce the risk in laterite volume estimation to acceptable levels. Surface geological mapping, high resolution topographic data and other information such as ground penetrating radar (GPR) can be used very effectively to improve volume estimates. These data types are all differently structured, have different data density and quality and may potentially overlap. Integration of these disparate data types provide the most cost-effective approach to modelling wet tropical nickel laterite volumes and minimising risk.

INTRODUCTION

A mineral resource estimate is the culmination of many study aspects that ultimately combine to define metal content of the deposit and its distribution in three dimensions. Each estimate must include three fundamental parameters, namely: grade, density and volume.

In addition there are other aspects, such as metallurgy, marketability and mineability, which may also play an important role for some deposits.

Despite the importance of these three basic elements of a resource estimate, it is common for resource estimates to be completed with dominantly only one data type provided as input, namely a drill hole grade database and associated geological logs.

Over recent decades there have been significant improvements in drilling, sampling and methods of geochemical analysis. Higher analytical accuracy and relatively lower cost for drilling and analysis, along with faster turnaround time have allowed drill hole sampling to dominate exploration programs. Quality assurance practices for geochemical analysis have improved and are now commonplace and have become an expected component of any resource estimate.

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Density is an important component that is typically under-sampled and poorly assessed. Though it has a very obvious impact on resource tonnage, density can also impact grade estimates directly where there is a correlation between density and grade. In contrast to geochemical sampling, resource estimates are commonly based on a small number of density measurements, using a single measurement method with no quality control or validation. Density estimation is typically one of the weakest components of many resource estimates and an area where the industry still needs to improve its practices.

Volume estimates can be derived from a number of data sources or methods. Such methods include cross-sectional interpretations, triangulations, grid models, geostatistical estimates of thickness or simulations. Unfortunately, many resource estimates rely solely on interpreted geological boundaries based on the same drill hole samples used to estimate the grades. Other useful information remains uncollected or is left languishing, unused.

This paper discusses the importance of resource volume estimates and when the benefits of using a wider range of data types by building geological or domain interpretations. An example of a generic wet tropical nickel laterite is used to illustrate these options since this style of deposit is particularly sensitive to volume estimation error or bias.

NICKEL LATERITE

Nickel laterite deposits develop from intense weathering of ultramafic bedrock. As with all laterites, the processes of weathering, leaching of some elements (such as magnesium and silica) and residual enrichment of others (such as aluminium and iron) requires a relatively long stable period of very wet conditions (Golightly, 1981). Highly soluble elements, such as magnesium, are dissolved and commonly removed from the laterite, whereas other elements such as nickel and cobalt may be reprecipitated and enriched.

Nickel laterite deposits, where they have not been truncated by erosion, can be crudely subdivided into two basic zones that overlie the basement rocks: an upper limonite or oxide zone and a lower saprolite or silicate zone (Golightly, 1981). The oxide zone is typically dominated by fine grained iron oxides and oxyhydroxides such as limonite, goethite and haematite. At the top of this zone primary textures are generally not preserved, but towards the base of this zone some remnant saprolite textures may still be evident. The silicate zone commonly contains assemblages of serpentine, chlorite and smectite-group minerals. The base of the silicate zone may include a transition zone with increasing proportion of weathered rock or mixed rocky boulders, grading down to unweathered basement.

The younger, less mature wet tropical laterites, such as many of those in south-east Asia, are usually thin (<20 m) and exhibit a rapid progression from the fine oxide zone into the bouldery silicate one. The older more mature laterites, such as those in Australia, are commonly much thicker and have more complex and variable silicate zones.

Wet tropical laterites commonly occur in tectonically active areas where high rainfall and lateritisation is still ongoing. This influences a number of characteristics of nickel laterite deposits that impact on the estimation of resource volumes, which include:

- topography;
- erosion;
- bedrock characteristics such as mineralisation, alteration and structure; and
- groundwater and surface water flow.
**RESOURCE VOLUME INFORMATION**

Volume estimates can be derived from numerous sources or influences. Four of these are elaborated below.

**Drilling**

For wet tropical laterites the saturated limonite clays are generally sticky, making percussion drilling difficult or prone to sampling error. Most wet tropical deposits are typically drilled by portable diamond core rigs with core diameters from NQ to HQ.

Variations in the laterite thickness can occur due to topography undulations, erosion, re-deposition, bedrock pinnacles or bedrock structure. In addition to variations in thickness, there are also variations in material type, where rocky material may be surrounded by finer clay material.

The relatively narrow gauge of the drill core only provides a very small limited representation of the laterite profile which can vary significantly, even at very short distances. Though drilling provides the foundation for grade estimation it is not necessarily a reliable indicator of local volume.

**Topography**

The quantity and quality of topography data can vary for wet tropical laterite deposits. Despite the poor soil quality, tropical nickel laterites can support thick rainforest inhibiting topography data collection.

Topography data can be derived from various sources, including regional photogrammetry or shuttle radar (SRTM) to more accurate ground-based survey such as total station. Where accurate ground survey data is limited to only the drilling lines due to thick forest, deriving a reasonable topography model can be challenging in its own right.

In this case the accurate survey data can be augmented by including break lines such as ridge tops and creek lines derived, from other sources such as regional mapping, satellite photography, field notes, etc. Elevations can be assigned to the break lines from available survey data to provide average slopes for the break line data. This provides a basis for integrating qualitative elements into an improved interpreted model still based on quantitative survey data.

In more recent times the development of airborne laser methods (ie LiDAR) to collect vast quantities of accurate ground elevation data over forested areas has allowed very detailed and accurate topography models to be constructed (Harding and Berghoff, 2000).

**Mapping**

In the past, resource estimates were based mainly on quality mapping and limited expensive sampling. The improvement in drilling and assaying technology has increased the availability and effectively reduced the costs of data collection to the point where resource estimates are dominantly based on assay data sets.

Perceived higher costs of labour or limited time frames have seen the demise of mapping as a significant geological task to the point where detailed feasibility studies or mining are completed before mapping is seriously considered. The reliance on assays alone to define a resource is short sighted yet an increasing dilemma we face as an industry.

Wet tropical nickel laterite deposits are thin and extensive. Being draped over often mountainous terrain, they are particularly prone to erosion and abrupt truncation (Golightly, 1981). Detailed
mapping provides the confidence to extrapolate resource boundaries or provide a basis for interpolating volume estimates between drill holes. This is a particular issue in deposits which are dissected by creeks and where drilling is typically biased by field crews who move drill hole locations away from regular grid locations in wet or steep creek areas to neighbouring locations where laterite remains unaffected by erosion.

**Ground penetrating radar**

Wet tropical laterites usually have abrupt domaining based on chemistry, material type and mineralogy. These variations may have sufficient contrast to provide radar reflectors, which ground penetrating radar (GPR) can image very effectively (Queen *et al.*, 1998). Interpretation of the radar signal can delineate contrasting material types, which can potentially be used to aid both resource definition and mine planning.

GPR is a geophysical method that is acquired along traverse lines. The radar frequency for GPR provides an effective sample size of around the radar wavelength of one to four metres (Franké and Nobes, 2000). This is substantially larger than the diameter of exploration drilling and has the potential to provide a more robust estimate of the material depths used for resource estimation. GPR is also collected continuously along a traverse, providing a complete profile of depth interpretations rather than a series of separated point samples as provided by drilling data alone.

Like all geophysical methods, GPR relies on basic assumptions and interpretations. These assumptions include the radar velocity, which may vary across a deposit or even with depth, moisture and material types. Therefore, results from GPR surveys must be corroborated with quantitative data such as pits or drilling. Interpretations of the same data may vary and the ease of interpretation will vary across a deposit as the geology and weathering material types vary.

Managing these issues is the key to enabling GPR data to be used for resource estimation purposes. Integration of GPR into the resource estimate in some projects has previously been undertaken to:

- augment the definition of the depth of laterite below older drilling and pitting which was only undertaken in the upper laterite profile or to drilling refusal at the top of the rocky zone,
- to significantly reduce the exploration drilling program with lower drilling costs and shorter exploration period since GPR is both faster and cheaper to acquire than infill drilling, and
- significantly increase the detail of the distribution of various lithological units and weathered domains beyond that which can be defined by exploration drilling and hence improve the resource volume estimate and resource classification.

**DATA INTEGRATION**

All these geological data types provide a different quality, style and arrangement of the information. A reliable estimate of the resource volume can only be achieved with careful integration of these different data types and consideration of all available data is required or implied under resource reporting codes such as JORC (2004). Resource information potentially derived from these data sources include:

- interpreted drill hole domaining provides a series of discrete point information of real or known material type boundaries,
topography provides a three-dimensional surface model that should include off-section data and attributes,

mapping data provides fact or interpreted lines of outcrop over the topography which can be simplified to off-section lines or polygon data types in plan view, and

GPR data provides detailed interpretive section lines of the material type boundaries.

Each of these example data sets has a different data density, orientation and quality, which requires integration.

The first step is to establish if the quality of all the data is adequate or sufficiently reliable for resource estimation purposes. Interpretive mapping or GPR may need to be revisited, reinterpreted or even discounted in light of direct information provided by drilling or pitting. GPR in particular should be considered a semi-quantitative method and may need recalibration or reinterpretation under certain conditions to be considered reliable or quantitative. GPR also has top and bottom depth limitations and a tendency to possibly detect a secondary material type contrast if the one of the main material types are missing. The reinterpretation of such data based on reliable ground truthing from pitting, drilling or mapping is fundamental for it to be considered sufficiently reliable for volume estimation purposes.

Once the processes for finalising the data are complete, there may still remain certain areas where the data overlap or cross and any discrepancies may need to be handled with a documented and systematic process. This second reinterpretation process is required to ensure that the higher quality data prevails. It should not necessarily be presumed that drilling is the highest quality data for volume estimation purposes; even though it is the most quantitative and reliable, the narrow gauge of the drill core means that GPR or mapping intrinsically has a vastly superior sample size.

The final step in modelling the volumes is to account for the different attributes of the data being used. The modelling of a laterite boundary surface should account for:

- The different data densities in a data set. For example, this could include 50 m grid drilling points, 1 m spaced interpretive points along a GPR section line and irregularly spaced points along mapped boundaries. Most grid modelling systems cannot adequately account for line data or the mix of point density between the different data type because they are essentially a statistical point processing method. Ways to obviate these problems can include careful point filtering or insertion to even out the point weighting, masking in plan view for mapping, or complicated gridding methods using residuals to sequentially include each data type. For triangulation modelling methods which honour all points and lines there are usually issues when line data points are too close to each other and the model cross-connects three vertices from the same line. Most modelling software packages still have no option to avoid this dilemma and require manual intervention or control strings to rectify the potential bias.

- Topography data and models are typically very detailed compared to the sparser geological information that is typically restricted to cross-sections. Yet topography is a major control on laterite formation and the thickness of the various horizons, since it controls erosion and water flow (Golightly, 1981). Incorporating the off-section topography elements into the geological model is the most difficult step in a laterite resource model and will always present issues. The appropriate modelling method depends on the degree of undulation in the topography and the underlying resource or geology boundaries. Something often ignored is that all surface modelling methods, whether gridding or triangulation, will rely on the closest data points. Since most geological data are often arranged along sections the modelling trend will be perpendicular
to the section line. However, topography trends will rarely be in this orientation and furthermore will change across a resource. Incorporating the variable topographic trends into a geological surface model will vastly improve the geological volume estimate.

**CONCLUSION**

Resource volume estimates are critical to reliable resource estimates. Surface deposits such as nickel laterites are partially sensitive to volume estimation, where it is critical to capture and incorporate all data into the geological model including:

- drilling and pitting data,
- detailed reliable topography data,
- qualitative data to augment any gaps in the available data,
- detailed surface mapping, and
- additional information such as GPR.

All too often the acquisition of integral data, such as surface mapping, is carried out too late to aid in the exploration and definition process, or useful data is under used in the blind belief that drilling alone is sufficient to define a reliable resource estimate.

In summary, the author would suggest that resource estimates should not rely solely on drilling, but instead on:

- collecting all potentially useful data,
- assessing it, and
- using it whenever possible.

**REFERENCES**


