Geotechnical Implications of Tropical Weathering Profiles in Iron Ore

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Abstract

Geotechnical investigations and conceptual mine design often relies on scant or interpreted data at the feasibility or pre-feasibility stage. It is regularly dependant on geotechnical information gathered from resource focused drilling which may not extend significantly into the final walls of the pit. It is therefore important to develop a reasonable engineering geological model of the significant geotechnical units which will have an ultimate effect on the pit design.

Development of an accurate weathering profile can be critical to domaining of zones within the model to apply slope angles in design, and as the slope angles applied within this weathering zone are often significantly lower than those in the fresher rock below, which can have a sizeable impact on the strip ratio, blasting requirements and waste volumes generated. In many cases this weathering profile within the waste material is not developed as part of the resource model wireframing.

There are a number of tools available to the geotechnical engineer to generate this profile. Although this is by no means an exhaustive list, recent studies conducted have employed available data from parallel studies, including geophysical and geochemical interpretation in areas where no specific diamond drilled geotechnical data is available, as well as an understanding of the restrictions and controls involved in the formation of the weathering profile and influence of both the country rock and iron ore body itself on the depth and shape of the weathering surfaces.

This paper discusses the various techniques employed to develop these weathering profiles from the limited data available, citing examples examined of large African Iron Ore deposits.

1 Geotechnical model

There is traditionally little geotechnical information gathered prior to the pre-feasibility stage of a project, to which point all drilling and resources are focused on defining the deposit. As such, there is frequently little geological information regarding the waste materials which will form the final pit walls. Often, even where drilling is available, waste units are not subdivided, either by geology or weathered state. It therefore falls to the geotechnical engineers to form a geotechnical domain model using all available information.

In tropical weathering regions, the contact between highly weathered soil strength material and slightly weathered rock is commonly very sharp – occurring within a matter of meters as can be seen in the example in Figure 1.

2 Implications of weathering depth

The depth of weathering can have a significant impact on the pit profile and stripping ratio of iron ore pits especially in deeper magnetite deposits. For example, Figure 2 shows the variation in overburden volumes generated for nominal pit diameters at a fixed overburden slope angle ratio of 3H:2V.

This volumetric increase can have a significant impact on pit economics in terms of strip ratio, waste volumes generated, haul distances and infrastructure placement and may be critical to a marginally economic project.
Figure 1. Weathering contact.

Figure 2. Overburden volumes generated at varying weathering depths for nominal pit diameters.
3 Case study 1: West African Haematite deposit - Guinea

A pre-feasibility study was conducted on a large haematite deposit in Guinea, West Africa. Due to the presence of some large structures, the phyllitic wall rock material was deeply weathered, however little was known of the true depth to fresh rock on the flanks.

With few diamond holes available, and the foreknowledge of some deep cross cutting structures evident from the geological modelling of the ore body, an attempt was made to correlate the rock strengths associated with the more weathered materials – problematic as they typically displayed low shear strengths – to RC samples from nearby drillholes as there was a volume of available RC drilling within the waste material, although no distinction in material state was made in the original logging.

Rock strengths ranged from R0 in the completely weathered, to R3 in the fresh phyllitic material, with the critical point of material susceptible to slaking from field tests lying within the early R2 range. Correlations between nearby RC and DD holes are shown in Table 1. A total of 13,000m of RC drill chips were logged in this way and a tentative waste material weathering profile developed.

Table 1. Strength correlations between diamond core and RC chips in Phyllite.

<table>
<thead>
<tr>
<th>Description</th>
<th>Rock Strength</th>
<th>UCS (MPa)</th>
<th>Field Estimate (core)</th>
<th>Field Estimate (RC chips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Strength Phyllite</td>
<td>R0</td>
<td>0.25 - 1</td>
<td>Thumb can indent</td>
<td>No clasts present</td>
</tr>
<tr>
<td>Very Weak Rock Strength</td>
<td>R1</td>
<td>1 - 5</td>
<td>Can be shaped by knife</td>
<td>Very rare clasts present. Small and well rounded - crushed in fingers</td>
</tr>
<tr>
<td>Phyllite</td>
<td>R2</td>
<td>5 - 10</td>
<td>Knife cuts, can't shape. Hammer pick indents &gt;5mm</td>
<td>Some clasts present. Well rounded and can be crushed by knife</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 - 25</td>
<td>Hammer pick indents &lt;5mm</td>
<td>Some clasts present. Rounded to Sub-Angular. Usually crushed by knife</td>
</tr>
<tr>
<td>Moderately Strong</td>
<td>R3</td>
<td>25 - 50</td>
<td>Geological pick may indent 5mm or needs hard blow to break. Knife just scrapes surface.</td>
<td>Sub-Angular to Angular clasts present. Clasts can be crushed on a hard surface by a geological pick</td>
</tr>
<tr>
<td>Phyllite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 Case study 2: West African Haematite/Magnetite deposit – Sierra Leone

Conversely, the weathering profile is not always of critical import. In this case study, the impact of the depth of weathering was low due to the steeply sided nature of the deposit, and shallow profile of the weathered material. Unlike the gradational weathering in case study 1, the contact between highly weathered (low shear strength, prone to slaking) and slightly weathered material is sharp, being less than ten – and often less than five – meters in width. Comparative mining models showing the determined range of weathering depth indicated that there was little influence from this feature and an extended study was not undertaken at the pre-feasibility stage.

5 Case study 3: Central African Haematite/Magnetite deposit – Congo

In this case study, there was little information regarding the depth of weathering prior to the pre-feasibility study. Due to the steep sided nature of the deposit and forestry clearance regulations within the Congo, it was not possible within the timeframe of the pre-feasibility study to drill flank holes away from the deposit ridge to profile the weathered zone of the flanking amphibolitic and granitic materials.
Likewise, although soft clays were encountered in trial pitting and shallow portable drilling for infrastructure, due to the positioning of the diamond drill holes on the ridge, drilled from within the deposit the waste was primarily encountered at depth showing dominantly fresh material on the flanks of the deposit.

Mining studies showed the economics of the deposit to be sensitive to the depth of weathering, both from the perspective of waste volumes generated, and infrastructure placement from the crest of the pit. Therefore, a conceptual model of the weathering profile was generated.

In this aim, two methods were employed:

- Ultra GPR lines were experimentally run in an attempt to define the depth to the base of the highly weathered material. As with case study two, the boundary between highly and slightly weathered is sharp and only a few meters in width. With the portability and easy access of the GPR set-up, this non-invasive technique is eminently suitable to the situation. Early results were encouraging, with the base of the highly weathered material evident.

- A second and more comprehensive technique was employed using the geochemical signatures from RC assay sampling, twinned with nearby (un-assayed) geotechnical holes. Estimates of weathering depth made from the diamond holes and the corresponding geochemical signatures assessed.

Although a bulk of the geochemical data lay within the ore body, studies showed a distinct correlation between the base of the weathered material and some of the chemical signatures as are shown in Table 2 and Figure 3 below.

The final weathering profile generated allowed the reduction of the pit footprint and waste volumes generated from the initial conservative profile generated.

![Figure 3. An illustration of the geochemical signatures of weathering in one drillhole.](image)
Table 2. Geochemical signatures of weathering.

<table>
<thead>
<tr>
<th>Weathering</th>
<th>Mg%</th>
<th>Ca%</th>
<th>K2%</th>
<th>Na%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW/HW</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MW</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SW/UW</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

6 Summary

Through observation of a number of deposits, and where no large structures have influence, a correlation can be drawn between the depth of friable ore, and the depth of weathering in the surrounding waste material, although a horizon of more weathered material is frequently seen abutting the competent ore.

Although not an exact science, employment of available, non-geotechnical data in generating a geotechnical model has proved invaluable. Other sources of information not discussed here include drilling logs, which if sufficiently detailed can show drilling rates or bit changes when moving from highly to slightly weathered materials in some sharply contacted weathered profiles, as well as detailed assessment of hydrogeological, structural and geological models which often show correlations to weathered profiles even whilst not modelling them specifically.

Integration of related disciplines and ideas is key to maximising the potential of the information available at the early stages of an investigation.