Density – Neglected but Essential

The poor orphan in mineral resource estimation

Andrew Scogings, Grant Louw and Bill Shaw
Setting the scene
Presentation outline

• What is bulk density? – Andrew Scogings
• QAQC and JORC requirements – Bill Shaw
• Methods and examples – Andrew Scogings
• Correct calculation of volumes – Grant Louw
• Conclusions – Bill Shaw.
Density

Underestimation of density will have consequences
‘We always dig out more than we expected’

<table>
<thead>
<tr>
<th>lbs/cu ft</th>
<th>t/m³</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>94</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>1.8</td>
<td>24%</td>
</tr>
</tbody>
</table>

Conservative density

Actual density
### What is it?

<table>
<thead>
<tr>
<th>Term</th>
<th>Units</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>none</td>
<td>Relative density: the ratio of the density of the material to the density of water at 4°C</td>
</tr>
<tr>
<td>Density</td>
<td>t/m³</td>
<td>Mass per unit volume</td>
</tr>
<tr>
<td><em>In situ</em> bulk density (ISBD)</td>
<td>t/m³</td>
<td>Density of the material in place, including the natural moisture content</td>
</tr>
<tr>
<td><em>In situ</em> dry bulk density (ISDBD)</td>
<td>t/m³</td>
<td>Density of the material in place, after all free moisture content has been removed. In JORC reporting, a metal assay (e.g. g/t Au) is assigned to the dry tonnage.</td>
</tr>
<tr>
<td>Loose bulk density</td>
<td>t/m³</td>
<td>For bulk sampling where the swell factor must be considered for material that has been extracted.</td>
</tr>
</tbody>
</table>

Adapted from Lipton & Horton (2014) – AusIMM Monograph 30
Why measure bulk density?

Three fundamental inputs to a Mineral Resource:

• Grade
• Volume
• Density.
Measuring three components

- **Mass** – usually the easy bit
  - Weigh and dry samples for moisture content
  - Weigh samples in air and water (Archimedes method)
- **Volume** – the difficult bit
  - Accurately measure the volume of the weighed sample
  - Do it early before the sample deteriorates
- **Moisture** – often inconsistently done
  - Consider if the samples are affected by seasonality and/or drilling fluids
  - Seal the samples early.
Density measurements should be treated like assays

- Assays must be defined and interpolated within consistent domains, such as by weathering and lithology
- Assays need QAQC, i.e. defined Quality Assurance procedures (collection documentation, equipment calibration, alternative methods, umpire lab, etc.) and Quality Control data (standards, duplicates, statistical analysis of precision and accuracy).
### Section 3 Estimation and Reporting of Mineral Resources

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density</td>
<td>• Whether assumed or determined. If assumed, the basis for the assumptions. If determined, the method used, whether wet or dry, the frequency of the measurements, the nature, size and representativeness of the samples.</td>
</tr>
<tr>
<td></td>
<td>• The bulk density for bulk material must have been measured by methods that adequately account for void spaces (vugs, porosity, etc), moisture and differences between rock and alteration zones within the deposit.</td>
</tr>
<tr>
<td></td>
<td>• Discuss assumptions for bulk density estimates used in the evaluation process of the different materials.</td>
</tr>
</tbody>
</table>
QAQC for density measurements

• Density information provided in a Public Report under JORC (2012) should be supported by similar data analysis and discussion

• This includes descriptions of the method(s) used (QA) for moisture content and *in situ* dry bulk density, analysis of the frequency and representativity of the sampling and some discussion on the accuracy and precision of the data and the results.
Certification and recalibration of scales using standards

Standard weights
Ore, waste and dilution

- The expected Revenue for the project is determined by the ore value (metal content less losses in most cases). A bias in the density estimate is transferred directly to the contained metal ($metal = grade \times volume \times density$)
- The economic value of the project (NPV) is determined by the revenues minus the costs. The mining cost in open pit projects is largely determined by the cost to move the waste
- Density must be determined and assigned (or interpolated) in an unbiased way for both ore and waste to ensure that Revenue, NPV and Dilution are all correctly estimated.
Ore Control

An example of a Density sampling program to resolve tonnage reconciliation issues.

Density Sampling
Ore Samples: 171
Average: 2.13 t/m³
Max: 3.04 t/m³
Min: 1.7 t/m³

Top Waste Samples: 53
Average: 1.48 t/m³
Max: 1.69 t/m³
Min: 0.93 t/m³
Methods not addressed in this presentation

• Stoichiometry (e.g. nickel sulphides)
• Sand replacement method
• Direct measurement of density (Troxler)
• Downhole geophysics.
Methods and examples
There is a bewildering array of methods for measuring the volume of samples (as core, rocks, stockpiles, powders, etc)

- Water displacement – uncoated, wax, spray lacquer, cling wrap, vacuum pack, ...
- Calliper – whole core, ‘half’ core
- Core tray
- Pitting
- Pycnometer.
Cases

- Stockpiles and bulk samples
- Whole core
- ‘Half’ core – this will be explained.
Stockpiles and bulk samples
Test Pit

Test pitting for density
Stockpiles and bulk samples

Stockpile loose density (10% moisture) using a cubic metre box

Clay stockpile

Steel box 1m³
Whole Core
Whole core - competent

Graphitic gneiss
Whole core – problematic

Ni laterite
Whole core

‘Hair spray’

Spray lacquer

Chromitite

Beeswax

Beeswax
Whole core

Paraffin wax

Friable chromitite

Hotplate

Draining tray

Wax

Chromitite
Whole Core

Vacuum pack or cling wrap
Whole core

Calliper

Calliper
Whole core

Calliper – clay core

Hacksaw

Trimmed core

Shavings for moisture test
<table>
<thead>
<tr>
<th>Method</th>
<th>Density</th>
<th>Difference vs. Calliper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/cm³</td>
<td>%</td>
</tr>
<tr>
<td><strong>Oxidised pyroxenite</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calliper</td>
<td>2.49</td>
<td></td>
</tr>
<tr>
<td>Vacuum pack</td>
<td>2.52</td>
<td>1.5%</td>
</tr>
<tr>
<td>Paraffin Wax</td>
<td>2.57</td>
<td>3.3%</td>
</tr>
<tr>
<td><strong>Competent un-oxidised pyroxenite</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calliper</td>
<td>3.28</td>
<td></td>
</tr>
<tr>
<td>Archimedes</td>
<td>3.32</td>
<td>1.2%</td>
</tr>
<tr>
<td>Cling Wrap</td>
<td>3.19</td>
<td>-3.0%</td>
</tr>
<tr>
<td>Vacuum pack</td>
<td>3.29</td>
<td>0.0%</td>
</tr>
<tr>
<td>Paraffin Wax</td>
<td>3.32</td>
<td>1.2%</td>
</tr>
</tbody>
</table>
Whole core

Robotic rig for photographing and weighing core in water
Half core
The cling wrap problem

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Size</th>
<th>Volume</th>
<th>Density</th>
<th>Method</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HQ core</td>
<td>203.61</td>
<td>2.16</td>
<td>Glad Wrap</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>HQ core</td>
<td>181.74</td>
<td>2.42</td>
<td>Wax</td>
<td>10.64</td>
</tr>
<tr>
<td>1</td>
<td>HQ core</td>
<td>181.31</td>
<td>2.43</td>
<td>Calliper</td>
<td>10.95</td>
</tr>
<tr>
<td>2</td>
<td>HQ core</td>
<td>250.95</td>
<td>2.40</td>
<td>Glad Wrap</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>HQ core</td>
<td>235.28</td>
<td>2.56</td>
<td>Wax</td>
<td>6.34</td>
</tr>
<tr>
<td>2</td>
<td>HQ core</td>
<td>233.50</td>
<td>2.58</td>
<td>Unsealed</td>
<td>6.95</td>
</tr>
<tr>
<td>2</td>
<td>HQ core</td>
<td>239.19</td>
<td>2.52</td>
<td>Calliper</td>
<td>4.69</td>
</tr>
</tbody>
</table>

Bigger volume than other methods

Chromitite
‘Half’ core

‘Half core’ with incomplete cut
‘Half’ core

‘Half’ core - calliper
### 'Half' core

6% lower on average

<table>
<thead>
<tr>
<th></th>
<th>CLING WRAP</th>
<th>WAX</th>
<th>CALIPER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.28</td>
<td>2.45</td>
<td>2.40</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.78</td>
<td>1.94</td>
<td>1.88</td>
</tr>
<tr>
<td>Maximum</td>
<td>2.44</td>
<td>2.58</td>
<td>2.61</td>
</tr>
<tr>
<td>Count</td>
<td>18</td>
<td>10</td>
<td>18</td>
</tr>
</tbody>
</table>

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**Clingwrap vs Calliper**

- **Graph Description:**
  - Scatter plot comparing Clingwrap vs Calliper values.
  - Markers indicate individual data points.
  - The red dashed line represents a 1:1 relationship.
  - The line of best fit suggests a linear relationship between Clingwrap and Calliper values.
  - The data points are generally aligned along the 1:1 line, indicating a consistent ratio or relationship between the two measurements.

- **Observable Trend:**
  - The data points are close to the 1:1 line, suggesting that on average, Clingwrap values are 6% lower than Calliper values.

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**Additional Notes:**

- The table data indicates a measured difference of 6% on average, suggesting a consistent trend across the samples.
- The scatter plot visually reinforces this trend, showing a linear relationship with data points clustering around the 1:1 line.
### Cling Wrap, Wax vs Calliper

<table>
<thead>
<tr>
<th></th>
<th>Cling Wrap</th>
<th>Wax</th>
<th>Calliper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.28</td>
<td>2.45</td>
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<td>10</td>
<td>18</td>
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*Graph: Wax vs Calliper*

- **Caliper vs Wax**
  - Red points: Caliper vs Wax
  - Blue line: 1:1 line
Gas Pycnometer

Sample chamber

Sample vial
Checking density is important

Mass vs volume weighting: Barite & Quartz blend for drill mud

![Graph showing density vs barite percentage by mass](www.csaglobal.com)
Correct calculation of volumes is important
A cylinder has interesting geometric properties that allow the volume to be easily calculated.
‘Half’ core

‘Half core’ (it never is) with perpendicular ends

Core lost due to the saw blade width
‘Half core’ with perpendicular ends:

Core is lost when cutting with 3mm blade down the centreline:

- HQ ‘half core’ loses ~6% volume of the half core
- NQ ‘half core’ loses ~8% volume of the half core.
### ‘Half core’ mass loss due to saw blade (NQ core)

<table>
<thead>
<tr>
<th>NQ core (diameter 4.79cm)</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole</td>
<td>1,064 g</td>
</tr>
<tr>
<td>‘half’ A</td>
<td>489 g</td>
</tr>
<tr>
<td>‘half’ B</td>
<td>488 g</td>
</tr>
<tr>
<td>Blade loss</td>
<td>88 g</td>
</tr>
<tr>
<td>% Blade loss (whole core)</td>
<td>8.2%</td>
</tr>
</tbody>
</table>
‘Half core’ with an unknown radius (due to cutting losses)

- The Sagitta and Chord are used to calculate the end area
- The cylindrical section height is measured
- The volume can be calculated.
‘Half’ core

‘Half core’ with a cylindrical wedge at one end
Assume a 20cm piece of HQ core weighing 800g, that was cut down the centre line with a 3mm saw.

|                       | Assuming perfect half core and applying $\frac{1}{2}\pi r^2 h$ to calculate volume | ‘Half core’ measured with volume calculated using correct formulae |
|-----------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------
| Density g/cm³          | 2.53                                                                                 | 2.69                                                             |
| **For 4 million cubic metres** |                                                                                     |                                                                   |
| Million Tonnes         | 10.1                                                                                 | 10.8                                                             |
| **At a grade of 3 g/t Au** |                                                                                     |                                                                   |
| Million Oz             | 0.97                                                                                 | 1.04                                                             |
| **At a price of A$1,554/Oz and a recovery of 90%** |                                                                                     |                                                                   |
| Expected Revenue       | $1,363 million                                                                        | $1,450 million                                                   |
| **Value "Lost"**       |                                                                                     | $87 million                                                       |
Conclusions
Conclusions

Main points

• Mineral Resources and Ore Reserve estimates rely on grade, volume and density (for reporting tonnes)
• For density determination of representative samples, measuring mass is easier than volume
• Understand the errors in measuring core volumes!
• Methods chosen for determining dry bulk density should be appropriate, correct and validated, e.g. by using alternative methods
• QAQC considerations for density should be noted in Public Reports under JORC (2012) and similar Codes
• The Competent Person should be able to defend the conversion of volumes to dry (or wet) tonnes.
Thank you

16 September 2015