Deriving Quantitative Geological Information From Assay Data

Dave Lawie
Managing Director
ioGlobal

www.ioglobal.net
Introduction

● Multi-element assaying of samples is common in exploration, resource and grade control work

● Other phase-specific data such as ‘extractable’ Cu, sulphide sulphur, silicate Ni and carbonate carbon may also be collected.

● Using relatively simple tools, such data may be used to derive quantitative information for
  ● Rocktype identification,
  ● Stratigraphic correlation
  ● Hydrothermal alteration identification and quantification.
  ● Assessment of exploration ‘fertility’
  ● Estimates of key metallurgical performance parameters
Exploratory Data Analysis

Does not require statistics – or hypothesis testing
Exploratory Analysis

Point Density

“don’t show correlation coefficients without the scatterplots”
Exploratory Analysis

SiO2_pct : Al2O3_pct

K2O_pct : Al2O3_pct
Classification Diagrams

- Can be used to push classification onto data, or verify field relations and geological information
  - For example, some are used to assess tectonic setting, while others are used for rock-type assignment
  - Classification diagrams are commonly applied to igneous rocks, however many other diagrams exist.
- Importantly, you can create your own classification diagram
Classification Diagrams

- Rock type identification in deeply weathered terrain (after Hallberg 1984)

Based on the relatively immobile elements Ti, Zr and Cr, it was possible to discriminate between volcanic rock types in the Yilgarn.

The plot works because although mobile constituents are lost from the rock, immobile elements are conserved.

The concentration of the immobile elements changes, but their ratio does not.
Classification Diagrams
- TAS Plot

• Provides a classification scheme for volcanic rocks
• Vulnerable to alkali loss, prone to closure effects
Classification Diagrams
- Rock type identification (Winchester and Floyd 1977)

- ‘Immobile’ trace element formulation
- Classification scheme for volcanic rocks
- More robust than TAS against mobility of alkalis
- Zr/Ti is a proxy for Si, Nb/Y is a proxy for total alkalis
- Boundary positions debatable
Custom Classification Diagram

Hand Drawn Line

P$_2$O$_5$ vs Zr - Century, Stratigraphic Groupings

Upper Footwall Samples Segregate from Hangingwall

Data from Whitbread
Classification - Caveats

The processes that have led to their derivation should preferably be understood. Different diagrams can give different classification results for the same sample.

Things to watch out for: weathering, alteration, plotting irrelevant rock types on the diagram, closure effects of tri-plots, inappropriate data quality (eg, 4 acid vs fusion for Zr), adequate precision (esp. for divisors) and data too near dl.
Mineral Chemistry based Classification

- Data becoming more available, MLA-type technologies
- Adapt a “whole-rock” chemistry diagram
- Show spinel compositional variation
- Derive an empirical classification scheme for new data
Jensen cation plot (left) and modified version (right) with spinel nodes shown.

Spinel names abbreviated Mcr=magnesiochromite, Spl=spinel, Hcy=hercynite, Ghn=gahnite, Mag=magnetite.
Spinel data from Barnes and Roeder (2001) plotted on the modified Jensen cation plot.
Mineral Chemistry based Classification - Spinels

Creating a category from a point density contour
Mineral Chemistry based Classification - Spinels

Creating a category from a point density contour

Contour @ 50th percentile of point density
Empirically Derived Classification Fields – Classify New Data
Assessment of Exploration Potential

- Fertility Indicators
Anomalous?

Global Ni-MgO Background

Average Ni content for 0.5 % MgO interval

Data: literature and internet
Data Analysis - Lithogeochemistry - Fertility

Ni vs MgO

Colours:
- Albion Downs
- Marshall Pool
- Mount Clifford
- Mount Keith (CLU)
- Mount Keith (MKU)
- Waterloo
- Wiluna
- Yakabindie

Shapes:
- Default Shape

Sizes:
- Default Size

Basalt, Pyroxenite, Peridotite, Olivina

Normal Ni

MgO (wt%) [Locked]

Ni (ppm) [Locked]
Fertility Assessment - Model/Process Driven

Such diagrams are useful for rapidly assessing fertility of large areas, but ‘zones’ on such diagrams commonly vary greatly for different terrains

Source: The Ishihara Symposium: Granites and Associated Metallogenesis

Palaeozoic Granite Metallogenesis of Easter Australia – Phil Blevin (@ Geoscience Australia, 2004)

Isotopes – Fertility Assessment

- **Application of Sulphur Isotopes to assessing Fertility of ‘Sulphide’ Discoveries**

- **Simple to apply, robust IF adequate orientation carried out**

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of Samples</th>
<th>Isotopic Range</th>
<th>Outliers</th>
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<tr>
<td>Harmin</td>
<td>55</td>
<td>3.0 to 10.5</td>
<td>1</td>
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<tr>
<td>Talbot</td>
<td>36</td>
<td>3.0 to 9.0</td>
<td>2</td>
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<td>Osborne</td>
<td>79</td>
<td>3.0 to 7.5</td>
<td>1</td>
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<td>Trout Lake (mineralised)</td>
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<td>3.0 to 6.5</td>
<td>1</td>
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<td>Trout Lake (argilite)</td>
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<td>3.0 to 6.0</td>
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<tr>
<td>777 mine 1242 level</td>
<td>11</td>
<td>3.0 to 5.0</td>
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<td>Flin Fion</td>
<td>45</td>
<td>3.0 to 8.5</td>
<td>2</td>
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*Poster: IGES 2005 - “Application of sulphur isotopes to discriminate Cu-Zn VHMS mineralization from barren Fe sulphide mineralization in the greenschist to granulite facies Flin Flon – Snow Lake – Hargrave River region, Manitoba, Canada.” by Paul Polito1,2, Kurt Kyser1, David Lawie3, Steven Cook4, Chris Oates5*
Modelling Alteration
Geochemistry at the End of a Drill Rig

- Enlarging the size of the target by **quantitatively** measuring alteration and/or searching for palaeo-dispersion at the cover-host-rock uc, ie interface sampling.
- With sensible use of the above, drill spacing can be enlarged to the extent that many undercover areas can be prospected with a **sufficient degree of reliability**.
Identifying and Quantifying Alteration

completely  partly  entirely  mostly  pervasive  fully  speckled
relatively  wholly  partially  kind of  totally  absolutely  spotted
extreme  none  sort of  severe  dappled  flooded  unaltered
intense  reminiscent of  feeble  strong  incipient  absent  fresh
somewhat  patchy  moderate  persistent  utterly  mottled  weak

Data: Cliff Stanley
Quantifying Alteration – 2 Diagram Types

- **General Element Ratio (GER)** diagrams **Do Not** use a Conserved Element, but the denominator is chosen based on mineral stoichiometry e.g. K/Al vs. Na/Al
  - Use the position of points relative to mineral nodes on a GER diagram
  - Design your plots to put minerals found in background rocks in different areas to the minerals found only in altered rocks

- **Pearce Element Ratio (PER)** diagrams use a Conserved Element as the denominator e.g. K/Ti vs Al/Ti
  - Use the slope on a PER diagram to represent minerals
  - Distance from the origin is proportional to loss/gain
Lithogeochemistry – Alteration Modeling

EXAMPLE GER DIAGRAM
Potassic and Structural Water Controls

- K-Feldspar
- Biotite
- Muscovite
- Goethite (vector)
- Albite, Anorthite
- Kaolinite
- Chlorite (4,0)

OH/Al vs. K/Al
# Modal Mineralogy

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<th>COMMENT</th>
<th>qtz</th>
<th>kaol</th>
<th>musc</th>
<th>kspar</th>
<th>albite</th>
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# Chemical Composition

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<th>Rock</th>
<th>SiO2_ %</th>
<th>TiO2_ %</th>
<th>Al2O3_ %</th>
<th>Na2O_ %</th>
<th>K2O_ %</th>
<th>H2O_ %</th>
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<th>Fe2O3_ %</th>
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Lithogeochemistry – Alteration Modeling

CCPI (chlorite-carbonate-pyrite index) vs AI (alteration index)

Mineral names; ep-epidote, ca-calcite, chl-chlorite, py-pyrite, il-illite, ab-albite, adl-adularia.

Diagram after Gemmel 2007 and Large et al. 2001

Point size proportional to Cu content.
Lithogeochemistry – Alteration Modeling

Combination PER Diagram - Sb Overlay

- Muscovite
- Illite
- Ankerite/Dolomite
- Calcite

K/Al (Al-Na for Sandstones)
Ca/C

Priority Exploration Targets
Background

- Sb: <= 1
- Sb: (1, 5]
- Sb: (5, 10]
- Sb: > 10
Quantifying Alteration – 2 Diagram Types

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  • Use the slope on a PER diagram to represent minerals
  
  • Distance from the origin is proportional to loss/gain
Lithogeochemistry – Alteration Modelling

- Separate chemical variations due to fractionation from those due to alteration
- Avoid closure

Pearce Element Ratio Plot - Displacement Vectors

- K Bearing Phases with no Al
- K-Feldspar Control Line
- Muscovite Control
- Illite Control
- Al Bearing Phases with no K
PER Diagram

Alkali Feldspar Control Diagram

- Kspar
- Monz
- Albite
- Gran Musc
- Feld Clay
- Muscovite Control Line
- Kaol
Lithogeochemistry – Carbonate Alteration

EXAMPLE PER DIAGRAM
Calcium and Carbonate Controls

- Calcite Effect
- Ank/Dolo Effect
- Siderite Effect

Calcite
Ankerite, Dolomite
Siderite

Ca/Zr vs C/Zr graph showing the effects of different carbonate minerals.
Lithogeochemistry – Carbonate Alteration

Carbonate

Calcite Line

Dolomite/Ankerite Line

Ca/C Ratio Thematic Colouring

Colours
- Default Colour
- Ca To Carb Ratio to 1.5703517 [10.00%]
- Ca To Carb Ratio to 1.6806723 [20.00%]
- Ca To Carb Ratio to 1.8538961 [30.00%]
- Ca To Carb Ratio to 2.1233766 [40.00%]
- Ca To Carb Ratio to 2.3758864 [50.00%]
- Ca To Carb Ratio to 2.5945945 [60.00%]
- Ca To Carb Ratio to 2.8017242 [70.00%]
- Ca To Carb Ratio to 3.0 [80.00%]
- Ca To Carb Ratio to 3.4672897 [90.00%]
Integrated Workflow Example

Winchester and Floyd

Attribute Map (Colour, Shape and Size)
Complex Workflow Enabled Interpretation

Winchester and Floyd

Attribute Map (Colour, Shape and Size)
Complex Workflow Enabled Interpretation

![Basalt Control Diagram]

- Altered basalts
Complex Workflow Enabled Interpretation
Metallurgical Applications
Geochemistry – Geometallurgy
Carlin Style Mineralisation

Each block is assigned a predictive processing value that can be input into the block model.

Quantitative alteration mapping from assay data

Whole rock chemistry
Immobile traces
Classification diagrams
Consistent classification

Phase specific assaying

Diagram from: SEG Newsletter, No. 73, 2008
Geochemistry - Geometallurgy

Diagram: SEG Newsletter, No. 73, 2008

Getting the Geo into Geomet
Some Important Metallurgical Parameters Measurable by Assaying at the Sample Scale

- Refractoriness (e.g. CN-leachable to non-leachable metal)
- Preg robbing (e.g. activated carbon)
- Mineralogical variability (e.g. cassiterite vs. stannite)
- Clay content (affects material handling properties)
- Acid-forming & acid-consuming minerals (e.g. carbonates)
- Cyanicides (e.g. cyanide consumers such as Cu, Fe, Zn, Hg)
- Oxygen consumers (e.g. sulphide phases)
- Deleterious or toxic elements (e.g. P distribution in iron ore)
- Coarse Au distribution (nugget effect)
- Sulphate producers (e.g. oxidation of sulphides)
Copper assay data plotted on a molar Cu vs S diagram. Molar ratios of Cu to S and their ‘slopes’ for the diagram are provided in the table. The plotted data are shown as coloured point density regions.
Metallurgical Applications – Alteration of Ultramafic Rocks

Serpentine/talc/carbonate rocks

- Magnesite
- Antigorite
- Forsterite
- Talc

Serpentine/talc/ternary phase diagram

Colours:
- MgO_pct 10.00%->20.00%
- MgO_pct 20.00%->30.00%
- MgO_pct 30.00%->40.00%
- MgO_pct 40.00%->50.00%
- MgO_pct 50.00%->60.00%
- MgO_pct 60.00%->70.00%
- MgO_pct 70.00%->80.00%
- MgO_pct 80.00%->90.00%
- MgO_pct 90.00%->100.00%
Alteration of ultramafic rocks

Carbonation of a hydrated Mg-silicate phase (serpentine)

Hydration of olivine to form serp
3D Integration

Magnetic model isosurface colour modulated by gravity
CONCLUSIONS

- Quantitative geological information is easily extracted from assay data
- Applying existing methods in new areas yields useful results
- If you have the data – use it
- If you don’t have the assay data – it may be worth getting
- Cost is trivial cf that of obtaining the samples