Putting the “GEO” back in front of GEOmetallurgy

Importance of early implementation of quantitative mineral system characterisation, classification and modelling

Warren Potma, Scott Halley, Andrew Scogings, Serik Urbisinov, Carl Brauhart.

Thanks, also, to Hot Chili Ltd.
Integrated GEOmet / 3D Mineral System Characterisation Approach

Inputs
- Open-minded working hypotheses
- Informed Observational Geology
- 4 Acid ICP-MS Geochemistry
  Alt’n-Pathfinder-Litho-Geochem
  Calculated Mineralogy
- Mineralogy: Spectral, Petro & XRD
- Geophysics/Petrophysics
  Appropriate Quantitative Mapping &
  DH logging data capture
  Structure, MagSus, Density, pXRF, Acid
  Fiz, Hardness, quality photography...
- High quality data management
- Live (implicit) 3D models
  Simplified fit-for-purpose 3D models
  Lithology – Mineralogy –
  Payable/Deleterious Elements -
  Weathering – Rock Mass

Integrated GEOmetallurgy &
3D Mineral System Modelling

Applications
- Ground Selection
  Quantify strategic decisions
- Exploration
  Greenfields – brownfields – mine - shoot
- 3D Modelling
  Litho-structural – Alteration - Resources
- Metallurgy
  Quantitative 3D Mineralogy
  Truly Representative Met. Composites
- Mine Design
  Rock Mass Classification – Geotech –
  Blasting - Scheduling
- Process Design
  Optimisation – Scheduling - Blending
- Environmental
  Acid Mine Drainage – Mine Closure

Impact
- Cradle to Grave
  Unifying link
  across Mining Value Chain
- Philosophy: to
  provide critical
  knowledge
  EARLY in project lifecycle for
  maximum value
- Costs savings at every stage from
  improved decision making
- Early warning of fatal flaws and opportunities
Case for early implementation

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W. Potma: AUSIMM ORE 20/11/2018
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Productora: U? -> IOCG(U)? -> PCD?

Andesites 90 Ma
Granitoid
Porphyry Cu deposit (Tertiary)
IOCG deposit
Iron oxide (apatite) deposit

135 Ma Granitoid
Sediments
Rhyodacite

90 Ma Granitoid with porphyry apophyses

Andesites

Hot Chili Ltd.
Classification of Productora Alteration Mineralogy

Feldspar Na-K GER Diagram

- K-feldspar
- Na-feldspar
- Alkali feldspar
- Albite
- Muscovite
- Rhyolite
- Dacite
- Andesite
- Basalt
- Sericite
- Sodic calcic
- Advanced argillic
- Magnetite

Colour:
- Background
- K-feldspar
- Na-feldspar
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Exploration Value


3D Calculated Mineralogy Model

- identified problems with existing geological model
- changed exploration focus (twice), resulting in 3 new discoveries
- Resource increases from ~100Mt to ~260Mt, 90 Mt maiden Reserve
- Ultimately led to maiden porphyry copper discovery
- Directly impacted PFS outcomes
Rocoto Discovery
Productora Central Pit Area
Section 6821840mN

K-Spar Alteration Vector

18m @ 0.8% Cu, 0.2g/t Au, 193ppm Mo

97m @ 0.6% Cu, 0.1g/t Au, 222ppm Mo including:
25m @ 1.1% Cu, 0.2g/t Au, 342ppm Mo

86m @ 0.5% Cu, 0.1g/t Au, 226ppm Mo including:
8m @ 1.4% Cu, 0.3g/t Au, 384ppm Mo

Preliminary Central Pit Design

Feb 3 2014
Metallurgist:

“I want a representative bulk sample..... please”

Potassic Tourmaline Breccia Cu-Au-Mo Ore:
- Majority of ROM ore
- Variable hardness, density & abrasiveness
  - K-spar cement dominant - dense and hard
  - Tourmaline breccia - soft, friable, abrasive
- Highly variable weathering – ox-trans-fresh?
- Strong localised structural/breccia controls (GC complexity)
Habanero Ore Zone:
• Anomalously E-dipping (Mining)
• Very high Cu grade (Mill feed variability)
• Locally high pyrite content (AMD)
• Relatively soft (Low BWI)
• Sericite + Clays (Float sliming?)
• Clay-rich shears & foliation (Geotech)
**Advanced Argillic Domain:**
- Silica-Clay (+/- sericite/pyrite)
- Dominantly waste – Pit high-wall
- Sharp E-dipping contact with HG ore (Mining)
- Deep weathering – highwall geotech
- Localised clay-rich shears/foliation (Geotech)
- Very hard silicification (Blasting/Drilling)
- Abundant cavities in oxide zone (Water!)
When the horse has bolted....

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Client Requirements:
Deliver the “least complex 3D geometallurgical domain model possible” for a complex Sn-fluorite-Cu-W Skarn deposit that:

- has quantitative constraints sufficient to underpin confidence in an “Indicated” classification for the fluorite MRe (20% of project value)
- is representative of the critical domains affecting processing, including: lithological, alteration and ore mineralogy; oxidation and weathering-related mineralogy; hardness; abrasiveness; grain size and textural characteristics
- adequately informs metallurgical sampling strategy
- Delivers a reliable, quantitative, 3D GEOmet model as “required to underpin confidence in the Feasibility Study for this perceived marginal Resource”
Estimating Fluorite Grade using Ca:F ratios (fluorite stoichiometry)

Fluorite constitutes ~20% of Resource value, but there is a problem...

Fluorite (CaF$_2$) = 51.3wt% Ca, 48.7wt% F

Any point above the black line exceeds the maximum possible fluorite content based on Ca content.
GEOmet Protolith vs Logging

Clients Geological Model: based on detailed logging

Simplified Protolith Model: based on quantitative lithogeochemistry focused on mineralogy that might impact processing
Gangue Mineralogy Classification (alteration mineralogy)

Feldspar Na-K GER Diagram

Point Density

K-spar or Biotite

Muscovite

Kaolinite

Least Altered Granite

Least Altered Sediments & Mafics/Andesites

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Highest-grade Sn mineralisation is spatially correlated with Quartz-Topaz-Kspar (and/or Biotite)- Mt Skarn +/- Muscovite

- Lower grades occur with Sericite-Chlorite-Magnetite Skarn
- Gangue Mineralogy requires further simplification for GEOmet
The simplified GEOmet Domain Classification is based on gangue mineralogy characterisation (using ICP-MS, XRD, SWIR, petrography and logging data), and is simplified to focus on critical attributes that potentially impact processing and mining.
Client’s detailed Geol. Model vs CSA GEOmet Domains

Client’s Geological Model:
- based on detailed logging

Simplified GEOmet Domains
- that impact processing & mining:
  - based on quantitative gangue mineralogy
Note the steeply plunging shoot geometry of the Qtz-Topaz Domain (right)

Enveloped by the magnetite-rich Fe-Skarn Domain which also dominates the north-eastern end of the pit (below)

The remaining volume comprises Calc-Silicate Domain rocks (not represented)
Client’s Geol. Model vs Quantitative Weathering Domains

Clients Geological Model

Quantitative Weathering Domain Model

Intense Supergene Clay Domain

Transitional-Oxide Domain

Sulphide Domain

ORIG-TIRR

WCR-RUBB

WCR-CLY

MTS_GL_3_1

MTS_AND

MTS_MG

SAN

CLY

LOAM

WCR_GRN

WCR_PR_GRN

GRN

150m

Potma: AUSIMM ORE 20/11/2018
Cassiterite (blue) dominates the proximal high grade ore zones.

Relative abundance of Stannite:Cassiterite increases away from the main ore, usually coincident with very low Sn grades.
Characterise more, characterise earlier & test less

- Skarn GEOmet work positively impacted fluorite MRe, Met test work programmes, plant design, pit optimisation and scheduling
- and “demonstrated that most of the preliminary metallurgical test work (predating the GEOmet project) was essentially wasted” (Client’s independent consultant metallurgist)

Early implementation of integrated quantitative MS characterisation:

- High value exploration outcomes
- Saves time & money throughout the project life cycle
- Improves spatial representivity & confidence in models
- Provides early warning of threats and opportunities
- Reduces risk, minimises errors & rework
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Putting the “GEO” back in front of GEOmetallurgy: Can you afford NOT to do it?

CSA Global GEOmet Team:
Warren Potma
Andrew Scogings
Carl Brauhart
Travis Murphy
Jamie Robinson
+ many additional commodity-specific experts

Follow Us On:

For more information please contact:
Warren.Potma@csaglobal.com.au

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