Geometallurgy – Optimising the resource
Regina Baumgartner
Ore Dressing, Geometallurgy and Environmental Geochemistry of Mine Waste
Geneva – December 19th – 21st 2012

Agenda
For today...
Geometallurgy: integrating geology, mineralogy, metallurgy and mine planning to improve fundamental understanding of resource economics and viability.

- Definition
- Business strategy
- Sampling and data interpretation
- Use of mineralogy in geometallurgy
- Environmental aspects
- Building spatial models
Several definitions for geometallurgy exist. The view can be restricted or more broad, depending to whom you are talking.

Dunham et al. 2011

A cross discipline approach combining geology, metallurgy, and mine planning, geometallurgy is seen as the next logical advance in improving the design and operation of mining businesses.

When successful, the geometallurgical approach promises the ability to tailor mining and mineral processing development and operational options more closely to the characteristics of the resource with resulting lower costs (both capital and operating), improved recoveries and fewer project failures.
Definition

SGS (http://www.sgs.com)

Geometallurgy is the integration of geological, mining, metallurgical, environmental and economic information to maximize the Net Present Value (NPV) of an orebody while minimizing technical and operational risk.

Definition

Quantitative group (www.qgroup.net.au)

Geometallurgy is a cross-discipline approach with the objective of addressing some of the complexities associated with determining the value of a resource and therefore if it is economic to exploit.

By integrating geology, mining operations, mineral processing and metallurgy, geometallurgy aims to improve the fundamental understanding of resource economics.

Geometallurgy is relevant at both feasibility study and operational phases.
Definition

Lamberg (2011)

Geometallurgy combines geological and metallurgical information to create spatially-based predictive model for mineral processing plants.

Demands for more effective utilisation of orebodies and proper risk management in mining industry have emerged a new branch called geometallurgy.

It is not really a discipline itself because it is related to certain ore deposit and certain processing flow sheet and therefore it can be rather regarded as a practical amalgamation of ore geology and minerals processing.

Definition

Melissa Gregory and Sergio Pichott, SGA 2011

Geometallurgy is a rapidly expanding area of economic geology, and is simply defined as using detailed geological data to characterize ore types in a deposit. This needs to be done in such a way that metallurgists and process engineers can use the information to optimize mineral process design.

The geological data relevant to geometallurgy also provides insights into the processes responsible for orebody formation which results in advances in genetic orebody models. Both the mineral processing and geological aspects have implications for exploration and mining, providing justification for the application of geometallurgical studies in all stages of project development.
Definition

GeoMet Tech (www.geomettech.com)

Geometallurgy is the study of the drivers for metallurgical response of a deposit that lie in the geology and mineralogy of that deposit.

A strong geometallurgical approach to new project development or operational optimisation is to define variability of geology and mineralogy that exist within the proposed mine plan and then to develop a tailored process plant to the ore to be milled and an optimised mine plan given all other key project constraints.

The key first requirement is to define and characterise the geological and mineralogical variability that exists in the deposit. For new project development, this process should begin in early scoping phase and then continue through to project feasibility study.

Definition

SRK, Sweden (http://www.srk.se.com/sv/service/se-geometallurgy)

Geometallurgy incorporates the principles of process mineralogy and material characterisation as a tool for predictive metallurgy.

And so on…
Business strategy

Key points

- As seen, geomet is **multidisciplinary** and there is no fixed definition.
- The main final objective is to **understand the processing attributes** of geological material before treating them.
- A **value chain view** is essential in geometallurgy: from resource definition to marketing.
- **Risk** is upside and downside and is about uncertainty. Constraints interacting with variability.
- **Cultural change**: implementing and interacting.

QG, 2011
Historically

Discipline silos

Geology

Mine planning

Metallurgy

Economics

Integration

Geometallurgy

Integration is an important element in geometallurgy

- Proxies for value: we can’t measure precisely the “value” of each block from the block model
  - Historically, grade has been used as proxy:
    - Grade
    - Throughput
    - Recovery
  - We know that value is not only grade, throughput and recovery.
  - Geomet identifies the important proxies and ways to integrate them to make decisions.

QG, 2011
Historically

**Proxies**

- Geologist
  - Grade

- Mining engineer
  - Tonnes

- Metallurgist
  - Recovery

**Geometallurgy**

**Integration**

- All must talk the same language
- Have a common goal
- Be involved early in the projects
Geometallurgy

Knowing the orebody

- Ore body knowledge: we need to understand all the properties that will have a negative or a positive impact on the value
- All properties that impact on:
  - Blasting
  - Milling
  - CO₂ costs
  - Energy consumption
  - Mineability
  - Revenues
  - Penalties
  - …
- It is not only about ore: mineralisation and its environment is important, including waste rock, tailings...

QG, 2011
Knowing the orebody

Practitioners of the deposit

What does it include?

- Data
  - Drilling
  - Mapping
  - Geophysics
  - Mineralogy
  - Physical properties of rocks
  - Metallurgical recoveries

- Interpretations
  - Lithological/structural model
  - Domaining
  - Conceptual

- Knowledge
  - Models built on the interpretations

Aim of geomet: Creating and sustaining value, therefore must be linked to financial concepts by management and by specialists

QG, 2011
Value chain

Value destruction if not properly understood the model

If biased or inadequate, it is impossible to optimise the subsequent steps of the chain

Sampling and data interpretation
Sampling and data interpretation

- General considerations
- Sampling goals and strategies
- Sample types
- Considerations of sampling design
- Geomet measurements and tests
- How much is enough

Sampling, measurements, and testing

What are we sampling for?

- grade
- extraction
- Hardness
- mineralogy
- flotation
- comminution
- smelting
- filtration
- crushing
- blastability
- sizing
- electrowinning

Extraction process
Sampling, measurements, and testing

- Data and information do not come for free
- Desired feature of information
  - Validity
  - Relevance
  - Timeless
  - Accuracy and precision

- This must be related to:
  - Use of the information
  - Capacity of decision maker decide to use it
  - Resource which are in place to develop the decisions

Extraction process

Sampling, measurements, and testing

- Why are we sampling?
- How are we sampling?
- What will the sample be used for?

Once these questions answered we need to determine
- Type of measurements and tests
- Type of samples
- Size of samples
- Distribution of samples – number and spatially
- Scale of sampling

We sample for a purpose

Extraction process
Sampling, measurements, and testing

Speak the same language as your friendly metallurgist or mining engineer

- Sampling: language
- Sample: a small part or quantity intended to show what the whole is like
- Critical component: presents the most difficult problem, sets sampling parameters for all components.
- Domain: closed volume defined by certain attributes
- Bias: if a sample is different from the lot, there is some error
- Representativeness: good representativeness when bias is low.

Sampling strategy – level of measurements

- Level 1: input used in estimating process behaviour. Routine measurements: logging, assays, ...
- Level 2: indicators of variability and response. Measurements: specific geometallurgical test (cheap and abundant). Includes Ci, rougher flotation,…
- Level 3: defining control tests. Tests include A*b, BWi, SPI, leach test, flotation
- Level 4: extraction process static response. Throughput, recovery…

Walters, 2008
Sampling, measurements, and testing

Review of sampling goals

1. Understand the deposit
2. Plan in terms of value
3. Statistical representation for modeling (most commonly this is done, using grade.

To keep in mind:
- Presence of variability in terms of:
  - Value
  - Grade
  - Rock type
  - Mineralogy
  - Extraction process responses

Walters, 2008

Sampling type

Samples can be:
- In situ
  - Geophysics
  - Downhole measurements (density, conductivity, structural, assay)
- Extracted from orebody
  - Drill core and chips
  - Pit, tunnel, blast hole
- From the process plant
  - Pipes, belt...
  - Head sample, flotation tails

Walters, 2008
Sampling, measurements, and testing

Current practice

Some examples:
- Relatively small number of samples (20-200) for extensive physical testwork, for example bond work index, A*b, batch flotation
- Extrapolate results into large volume based on existing rock boundaries such as lithology, alteration, ore types

Some potential pitfalls:
- Sampling does not address variability
- No dynamic feedback to control ongoing work
- Rock boundaries conditions do not correlate with processing boundaries – they were never calibrated

Extraction process

Walters, 2008

Measurement and testing

- **Measurements** is made by the determination of characteristics of a material (chemical composition, mineralogy)
- **Testing** is measurement of responses in terms of a further application

QG, 2011
Sampling, measurements, and testing

Accuracy and precision

- Accuracy
- Precision

It is better to be vaguely right that precisely wrong (Keyes)

Measuring and testing

Rock properties

- Visual logging
- Routine assays
- Mineralogy from assay
- Mineralogy from XRD and spectral
- EQUOtip and sonic velocity hardness
- Core image analysis outputs

- GeM Commination Index Test
- JKRBT A*0 and BMWi estimates
- Other existing tests on site e.g. SPI or SMC
- Modified BMWi tests
- Full Bond and Drop Weight tests

Extraction process data

Amira, 2010
**Sampling, measurements, and testing**

**Proxies**

![Predictive geometallurgical models](image)

Walters, 2008

---

**Typical proxies: substitutes**

<table>
<thead>
<tr>
<th>Measurements/Test</th>
<th>How</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual logging</td>
<td>Observation</td>
<td>Lithology, alteration, mineralogy, geotech, texture</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>Visual Optical XRD Qemscan/MLA spectral</td>
<td>Minerals and abundance Mineral size distribution Mineral association Texture</td>
</tr>
<tr>
<td>Assays</td>
<td>XRF Aqua regia-ICP Multiple acid-ICP Fire assay</td>
<td>ElementaL, compounds, specialion, normative abundances</td>
</tr>
<tr>
<td>Traditional physical properties</td>
<td>Downhole logging Surface Laboratory Gravity Magnetic separation</td>
<td>Magnetic susceptibility Resistivity/conductivity Density Gamma, velocity</td>
</tr>
<tr>
<td>Other physical properties</td>
<td>Equotip imaging</td>
<td>Hardness texture</td>
</tr>
</tbody>
</table>

QG, 2011
Sampling, measurements, and testing

Conclusions

How much data do I need?
In summary, it depends....

Consider:
- Initial goals and objectives
- Proxies
- Spatial volume under extraction versus scale of extraction process
- Variability of response

Checklist

Variability
- Can you describe it numerically?
- Can you describe it spatially?
- Do you understand the drivers?

Purpose and focus – context
- Have you fulfilled the goals and objectives within the limitations and risk tolerance?
- Have you met the success criteria?

QG, 2011
The plant processes a mix of minerals, not just gold or copper or another valuable element.

A rock is an aggregate of minerals. When the rock enters the plant, the processing method will depend not only on the valuable mineral, but also on the gangue minerals.

Need to characterise in detail the ore, but also the waste.
Using mineralogy in geometry

**Methods**

- Visual logging
  - Routine and low cost but difficult to derive quantitative results. Every geologist has a different internal calibration
- Optical mineralogy
  - Best quality recognition but expensive and difficult to provide routine data
- SEM-MLA/Qemscan
  - Medium cost and needs a careful analysis of the spectra
- Quantitative XRD
  - Rapid qualitative technique but challenging if quantitative information is needed
- Spectral Reflectance
  - Cost effective but needs a good calibration with XRF and quantitative XRD
- Mineralogy from assays
  - Cost effective but needs a good calibration with XRF and quantitative XRD

**Factors to consider**

- Quality of sample preparation
- Measurements mode / parameters selected
- Sample representivity
- Particle size distribution
- Purpose

**Prepare and measure the sample**
- XRD, XRF, SEM, EDS, …
- Method
- Microscopic validation
- Standards

**Process the data by mineralogist**
- Particles
- Image processing
- Classification
- QAQC

**Manage the data, interpret and validate**
- Database
- Data analysis
- Representation

QG, 2011
Using mineralogy in geomet

Optical mineralogy

- “Academic” mineralogy looks at the paragenetic sequence
- “Industry mineralogy” looks at the texture, quantitative mineralogy, and size.

Using mineralogy in geomet

Qemscan/MLA

- Modal mineralogy
- Mineral size distribution
- Mineral association and elemental deportment
- Particle maps
- Texture
Using mineralogy in geotechnics

Modal mineralogy

- Provides a quantitative inventory of all minerals present in the sample

Mineral size distribution

- Provides the size of the overall minerals and the minerals of interest. This is important for flotation which effectiveness depends on grain size.
Mineral association and elemental deportment

- Mineral association is useful for analysing if deleterious minerals are present with the ore minerals.

Texture

- Locking and liberation
- Overall size of grains
Particle maps

- Helps in identifying differences or similarities among samples, for ore minerals but also for gangue.

Validation

- No method is perfect!
- Validation is needed. Qemscan data can be validated using:
  - Assays
  - XRD. Limitation: can’t validate minor phases
- Fine-grained minerals and boundary phases are always problematic.
- The scale matters
Using mineralogy in geomet

Spectral reflectance data

- Terraspec and Pima to identify clay minerals and other gangue minerals.
- Scanning spectral reflectance (such as corescan or hylgger)
- Technology is based on wavelength, which is characteristic for each mineral
- Limitation: not capable yet to determine sulphides, quartz and some silicates.
- Can be used in two ways
  - Point data
  - Scan data
- Determination spectrum
Calculating mineralogy from assays

- Mineralogy can be calculated from assays.
- Different techniques exist.
- Assay type will be important
  - AR assays
  - MD assays
  - Upper detection limits (Fe, S, …)
- Validation will be key
  - XRF
  - XRD
  - Qemscan

Ore and gangue

- Ore and gangue mineralogy is key.
- The plant, which includes crushers, mills, flotation cells, cyanidation, … will “see” all minerals in the rock.
- Each mineral deposit has internal variability not only in grade but also in gangue mineralogy, among others.
- Being able to predict mineralogy can be an upside and can prevent future surprises.

The mineralogy results will be as good as the mineralogist
Environmental aspects

Waste rock characterisation

- Geochemical waste rock characterisation can be expensive if waste rock is an issue, i.e. Acid Rock Drainage (ARD).
- Conducting tests on a large number of samples can be expensive.
- The geochemistry of waste rock will be variable and therefore, understanding this variability will be important.
- Main problems: samples taken in the immediate area from the open pit because the availability of samples is best there. We generally drill for resource, not for waste rock.
- This is where mineralogy and visual observations can be important.
- Also, please sample waste rock in routine assays. In a lot of cases, waste rock is not analysed.
The potential for acid rock drainage (ARD) from waste material is recognized as a key issue in project planning in the following areas:

- Mine planning and scheduling in the pit and waste dump(s),
- Waste material dump handling and treatment, whether it is surface or underwater,
- Pitwall and pit floor hydrology and ARD modelling,
- Tailings storage facility,
- Proper sampling for waste material characterization
- Reclamation and closure planning that essentially depend upon waste material removal,
- Use of waste material for construction
- Waste material blending
- Design of waste rock dump (and water treatment facility if needed)

A waste material estimate must be calculated in conjunction with the resource estimate because of the importance for mine waste disposal. ARD waste material includes overburden, waste rock, pit walls, pit floor and tailings, which should be classified as potentially acid generating (PAG), potentially acid consuming (PAC) or non acid generating (NAG/non-PAG).

The type of predictive ARD block model that is used should be decided by the resource practitioner. It will be used in long range planning and production decisions which ultimately lead to the estimation of the disposal costs associated with a block of waste rock.

Each waste block must be treated separately as to its mode of removal or salvage, placement and subsequent treatment.

There are two main components of the block model:
1) Estimate the acid generation potential of waste material, and
2) Estimate the metal or trace element component of the waste material that would impact the metal leaching (ML) component of the ML/ARD program.
Environmental aspects

Sampling

Number of samples depend on:

- Size of the deposit, better said, tonnages of waste rock
- Complexity of the geology (lithology and alteration)
- Presence of acid generators
- Presence of acid neutralizers

The sampling must answer the following question:

*Will the number of samples be sufficient in order to construct a waste rock block model that will characterize each waste block with some confidence?*

Analyses and proxies

- A suite of analyses for geochemical waste rock is available and include:
  - XRF for whole rock analysis
  - ICP for minor elements
  - Speciation of S and C
  - XRD for mineralogy
  - Optical mineralogy
  - ABA tests
  - NAG tests
  - Short term leach tests
  - Kinetic tests (humidity cells)

- These test will provide information to classify the waste rock.

- Once the classification is available, the exercise will be to extend this classification to the entire block model. Since the geochemical tests are costly, a low-cost proxy has to be identified. For example, the abundance of sulphur, lithology, alteration can be some of the proxies.
Environmental aspects

**Conclusions: waste is important!**

- Think waste, not only ore!
- Collect routine data for waste, not only for ore
- Drilling for waste is generally not a common practice. In feasibility or detailed design phases, it may be necessary to drill some hole. Neutralising potential rocks might be needed and might occur outside of the pit.
- Identify if any minerals could be an issue and generate ARD
- Find solutions or scenarios (options) as early as possible
- Identify if any risk could be a fatal flaw for the project

**Building spatial models**
Building spatial models

Spatial models must be tailored to be used by different people. The most conventional models used across disciplines is the block model.

A model is an interpretation of the theory. It has 3 main characteristics:

- Mapping features. A model is based on an original.

- Reduction features. A model reflects only a (relevant) selection of the original’s properties.

- Pragmatic features. A model needs to be usable in place of the original with respect to some purpose.

The task will be to build a model and integrate it.
A block model is a three-dimensional spatial representation to quantify the geology and economics of a deposit which in turn is used in mine planning.

- The block model will be as good as your geology, alteration, and structural models. If your understanding of the deposit is poor, the block model will be poor and far from the reality.
- The block model needs to honour geology and statistics using variograms.
- Each block of the block model will be estimated where information exists. The other blocks which contain limited information will have to be estimated with less confidence.
- Several techniques of estimation => not the topic of this lecture…
  - Ordinary kriging (OK)
  - Localised uniform conditioning (LUC)
  - Simulations
Building spatial models

**Domaining**

- Domaining is a first order decision and will influence all subsequent steps in estimation.
- It is usually necessary to partition the dataset into geologically and statistically domains.
- Lithology domains ≠ alteration domains ≠ comminution domains ≠ metallurgical domains
- For example, grade domains may not be suited to geomet variables.
- Each domains should have similar characteristics and should not present a too large variability. If there is variability:
  - The domain is wrong
  - Poor data quality
  - Nugget effect (in the case of a gold deposit)
- RISK: the sampling is poor and the variability is smoothed!

---

**Scenario world**

- The use of multiple spatial models (simulations) allows us to consider the impact of geometallurgy variability on multiple projects options.

---

QG, 2011
Applications of geometallurgy

No surprises

- Where
  - Greenfield projects
  - Operations
  - Expansions
  - Potential rejuvenation or projects

- When
  - Short term
  - Long term

- What
  - Understand in-situ variability
  - Process design sampling strategy
  - Planning and forecasting
  - Risk management

QG, 2011

Applications of geometallurgy

Deposit and requirement specific

- Geometallurgy needs to relate to:
  - The mineralisation, waste types, variability
  - The technology under consideration or in use
  - The potential risks

- Technology includes relevant tests

- There is no “sausage machine” approach. Every situation is unique

QG, 2011
The ideal approach is not what is done in the mining industry

One body knowledge → Multiple resource → Multiple options → Selection → Value

Single resource → Optimisation (?) → Value (sort of)

Or at best...

Single resource → Multiple options → Optimisation → Value (sort of)
Applications of geometallurgy

What is an option?

- Language comes from finance (put and call options, …)
- A real option is the ability to (but not obligation) to exercise a project decision in the future
- These options cost money, which buys flexibility (e.g. assaying for all elements, like Olympic Dam)
- If we do not value option, we cannot know the cost of foregoing them.
- If an option is valuable, we should exercise it as soon as practical.

Mendler and Odell, 2000
Applications of geometallurgy

What do we mean by optimisation

- Optimisation: the act of rendering optimal, seeking an optimum
- Optimal:
  - The best, more favourable or desirable, especially under some restrictions.
- Seek the highest NPV
- An optimal strategy is one which performs best against defined objectives.

Optimisation in mining

- In general, optimisation of a project or option involves seeking the maximum financial return (often, but not always NPV).
- An optimised project is not necessarily optimal or best, e.g
  - Are we optimising taking into account constraints?
  - Is the optimal NPV unduly sensitive to change in project parameters.
- Is the option robust? This is in general not evaluated.
- Robust: yielding relatively unchanged financial (or other) output in the face of changed circumstances.
- Two levels of robustness:
  - Robustness of a plan or project in the face of the orebody being different to the model (the unknown and dirty truth)
  - Robustness of a plan or project to changes in mining, treatment or financial parameters (can be engineered away)

QG, 2011
Applications of geometallurgy

Optimisation and scenarios

- Optimisation approach (multiple options, one orebody model, aggregated input; does not capture real variability)
- Scenario-based approach (multiple options, multiple orebody models, unaggregated – fine scale – input; captures real variability)
- It is complementary to optimisation
- It is a route to robust evaluation, seeks “plateau of value”, e.g. not looking at the highest peak but less sensitive.

What the resource model is NOT

- The truth
- Reality (it is a model)
- Free
Applications of geometallurgy

- Clay content and variability in heap leach and flotation cells
- Grind size and recovery / concentrate grade for base metals => ore dressing!
- Oxide / primary blend options for gold projects
- Stock pile management strategies and impact on feed variability (deleterious elements, clays…)
- Contrasting cut-off grade strategies

If the ore body knowledge is poor and you did not create flexibility

QG, 2011

Proactive rather than reactive

Dunham et al. 2011

QG (Quantitative Group), 2011, Geometallurgy – optimising resource value. 3 day short course, Santiago, Chile.

Walters, S, 2008, Geometallurgical matrix building, sampling, measurement and testing strategies – Cadia East site deployment, GeMII (Amira P843) Technical Report 1

Lamberg, P. 2011, Particles – the bridge between geology and metallurgy.