Geometallurgy – Optimising the resource

Regina Baumgartner

Ore Dressing, Geometallurgy and Environmental Geochemistry of Mine Waste

Geneva – December 19th – 21st 2012

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Agenda

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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

2

Definition

Definition

Several definition 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.

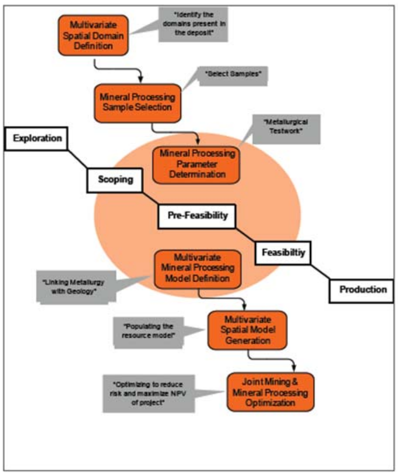
When successful, the geometallurgical approach promises the ability to tailor mining and mineral processing development and operational options more closely to the characteristics of the resource with resulting lower costs (both capital and operating), improved recoveries and fewer project failures.

4

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.



5

Definition

Quantitative group (www.qgroup.net.au)

Geometallurgy is a cross-discipline approach with the objective of adressing 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.

6

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

Business strategy

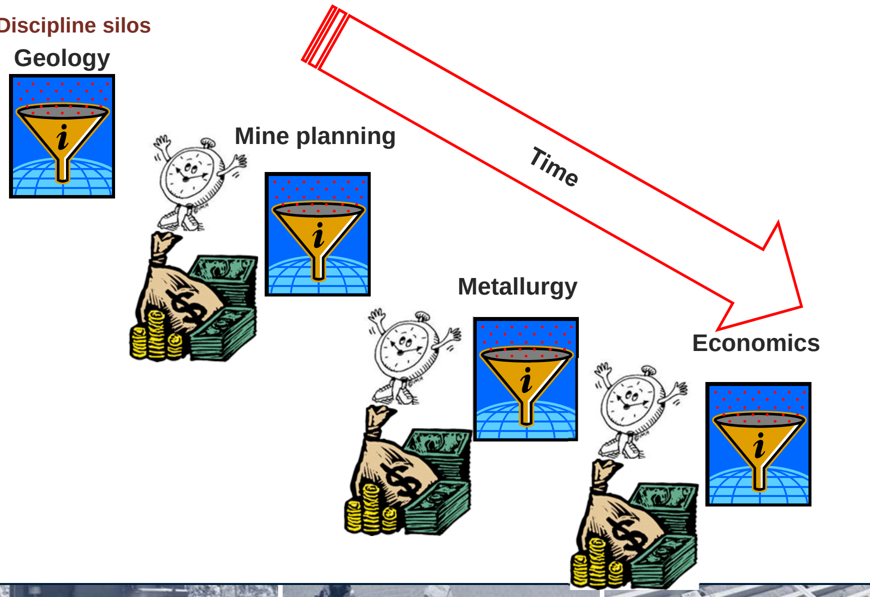
Key points

- 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

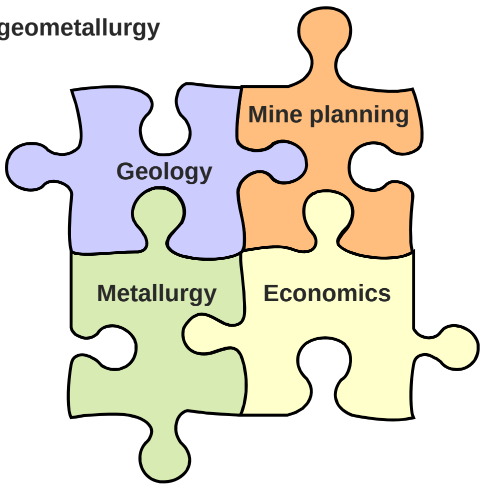


Geometallurgy

Integration

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.



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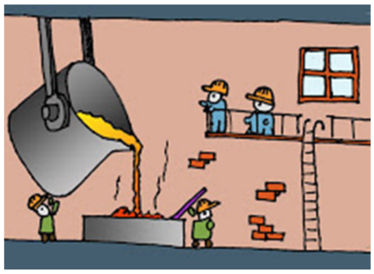
Historically

Proxies

- **Geologist**
  - **Grade**

- **Mining engineer**
  - **Tonnes**

- **Metallurgist**
  - **Recovery**



15

Geometallurgy

Integration

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

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16

Vann and Dunham, 2007

Geometallurgy

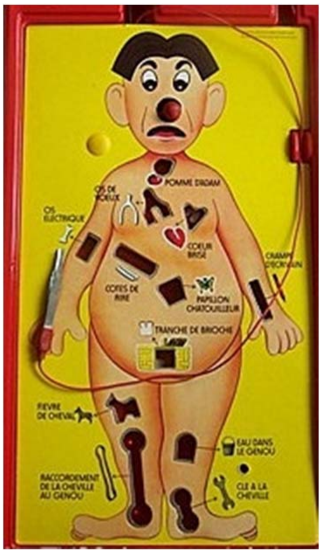
Knowing the orebody

- 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
  - CO_2 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



19

Knowing the orebody

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

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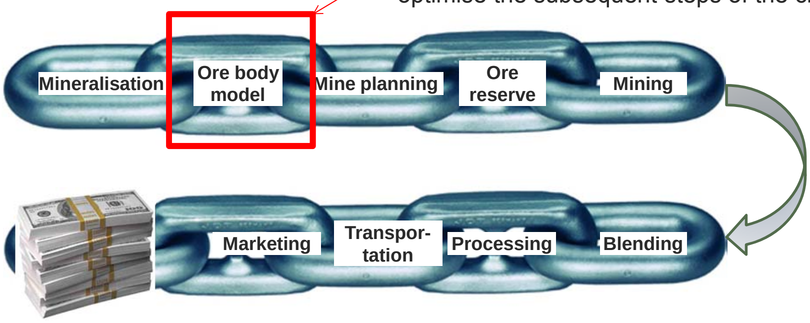
20

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



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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

roasting

flotation

comminution

smelting

filtration

crushing

blastability

electrowinning

sizing

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

QG, 2011

25

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

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26

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 representitivity when bias is low.

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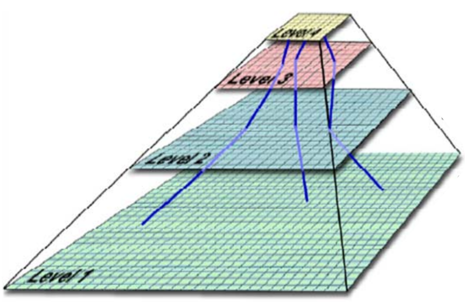
27

Sampling, measurements, and testing

Sampling strategy – level of measurements



Walters, 2008

Extraction process

- **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…

28

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

Extraction process

Sampling, measurements, and testing

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

Extraction process

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

Walters, 2008

Extraction process

31

Sampling, measurements, and testing

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

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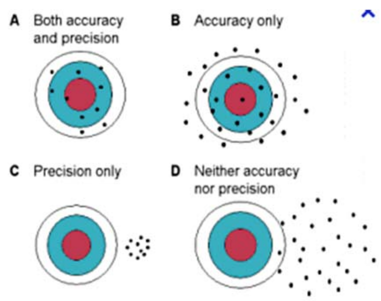
32

Sampling, measurements, and testing

Accuracy and precision

- **Accuracy**
- **Precision**

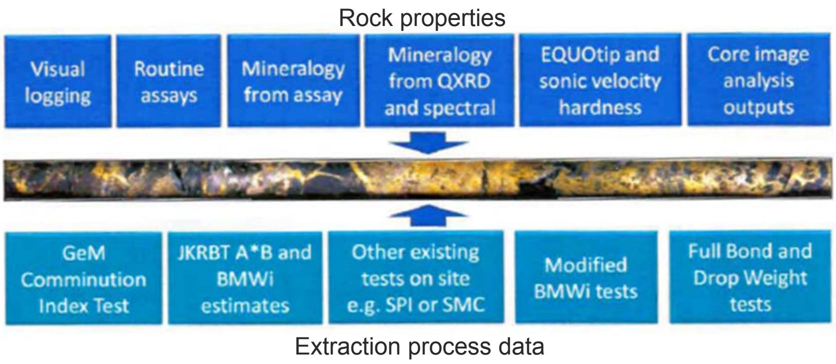


Jekel et al, 2006

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

Sampling, measurements, and testing

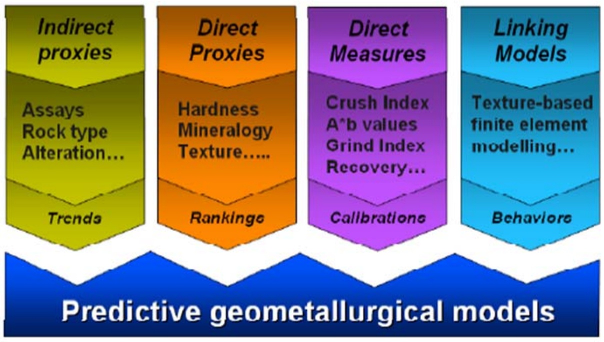
Measuring and testing



Amira, 2010

Sampling, measurements, and testing

Proxies



Walters, 2008

35

Sampling, measurements, and testing

Typical proxies: substitutes

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

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36

Sampling, measurements, and testing

Conclusions

How much data to I need?

In summary, It depends….

Consider:

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

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37

Sampling, measurements, and testing

Rigth and sufficient data

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?

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38

Use of mineralogy in geomet

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Using mineralogy in geomet

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The mine value is in the ore minerals. Waste has to be taken into account as well.

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 geomet

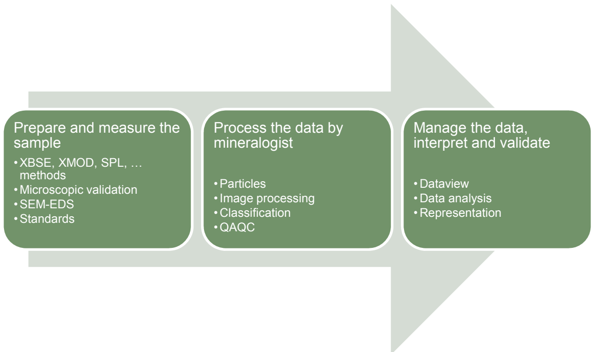
Visual logging	Optical mineralogy	SEM- MLA / Qemscan	Quantitative XRD	Spectral Reflectance	Mineralogy from assays
Routine and low cost but difficult to derive quantitative results. Every geologist has a different internal calibration	Best quality recognition but expensive and difficult to provide routine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

41

Using mineralogy in geomet

Factors to consider

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



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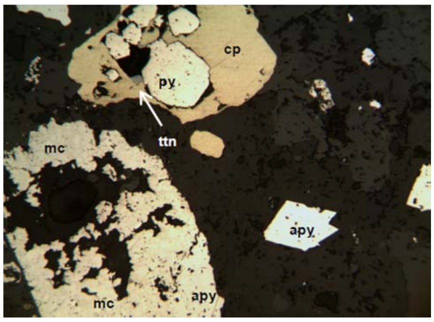
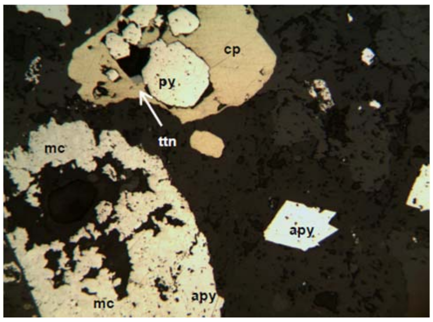
42

Using mineralogy in geomet

Optical mineralogy

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

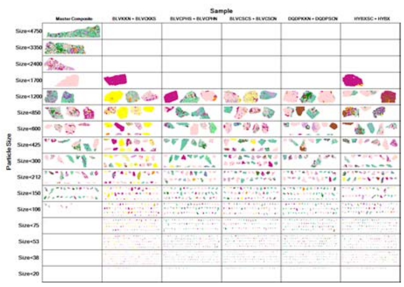


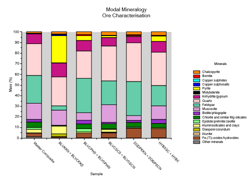


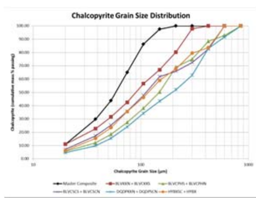
Using mineralogy in geomet

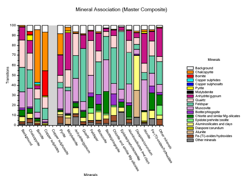
Qemscan/MLA

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





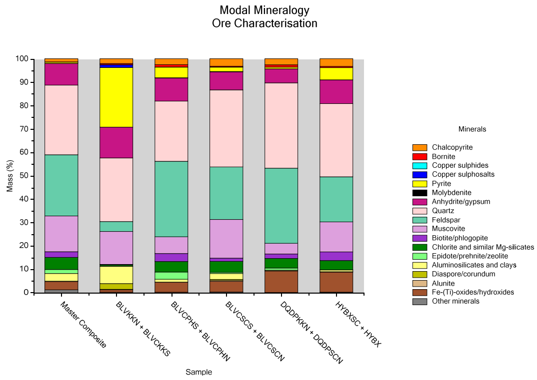




Using mineralogy in geomet

Modal mineralogy

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

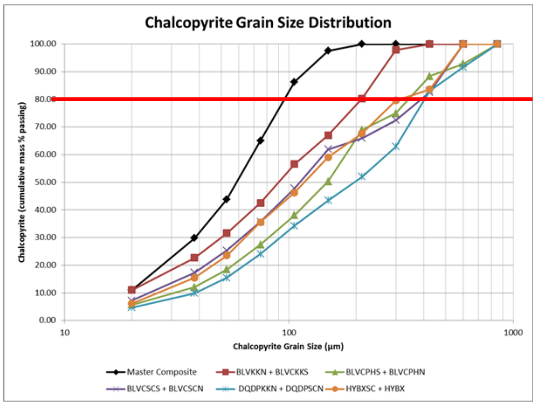


45

Using mineralogy in geomet

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.

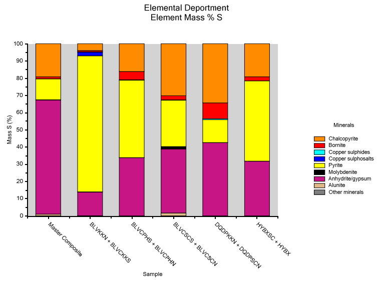


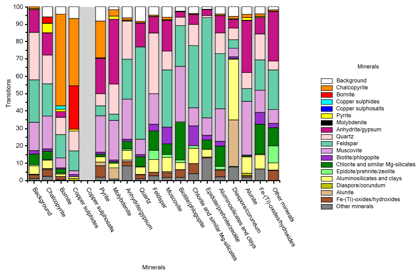
46

Using mineralogy in geomet

Mineral association and elemental deportment

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



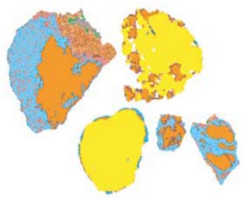


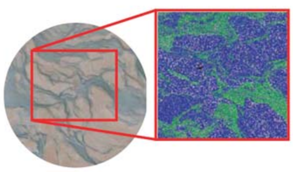
47

Using mineralogy in geomet

Texture

- Locking and liberation
- Overall size of grains



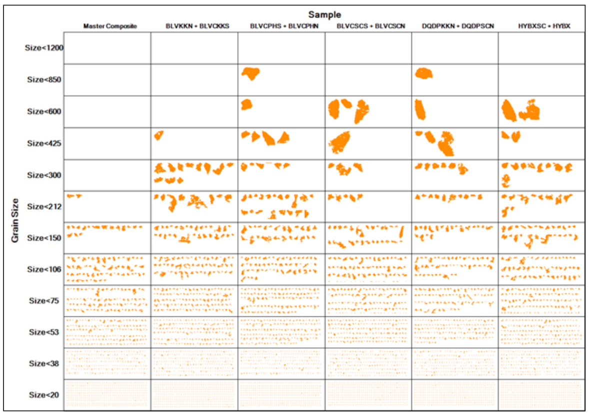


48

Using mineralogy in geomet

Particle maps

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

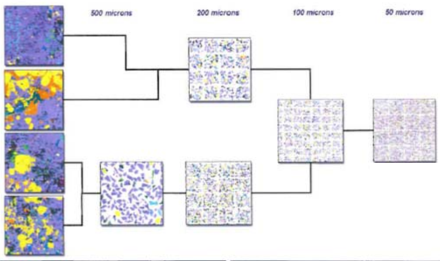


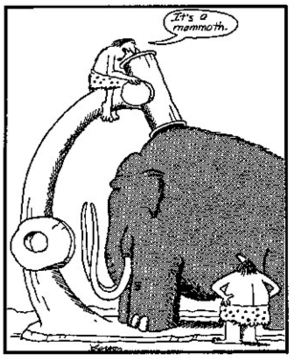
49

Using mineralogy in geomet

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





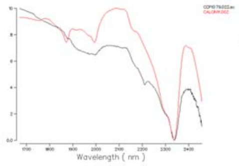
Early microscope

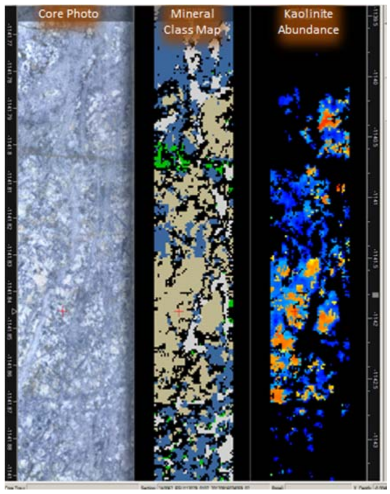
50

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 hylogger)
- 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 cessing





51

Using mineralogy in geomet

Spectral data

Vann and Dunham, 2007

52

Using mineralogy in geomet

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

53

Using mineralogy in geomet

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

54

Environmental aspects

Environmental aspects

Waste rock characterisation

- Geochemical waste rock characterisation can be expensive is 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 were 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.

56

Environmental aspects

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)

Environmental aspects

- 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.

Downing and Giroux, http://technology.infomine.com/enviromine/ard/Introduction/BlockModel.htm

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?

59

Environmental aspects

Analyses and proxies

- A suit 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.

60

Environmental aspects

Conclusions: waste is important!

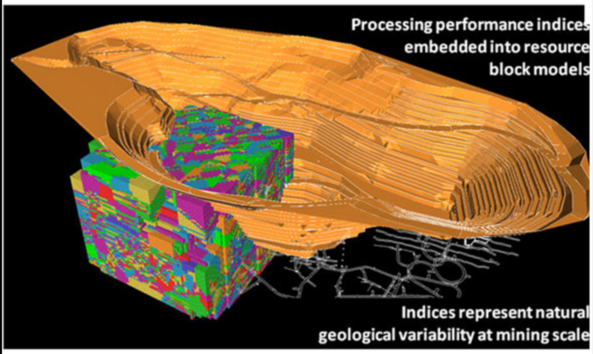
- Think waste, not only ore!
- Collect routine data for waste, not only for ore
- Drilling for waste is generally not a common practice. In feasibility or detailed design phases, it may be necessary to drill some hole. Neutralising potential rocks might be needed and might occur outside of the pit.
- 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

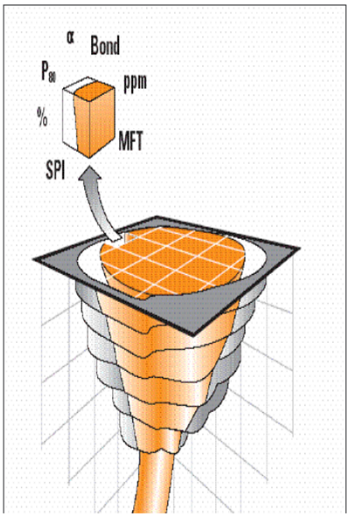
Building spatial models

Building spatial models

Populating the block model

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





63

Models

Building spatial model

What it a 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.

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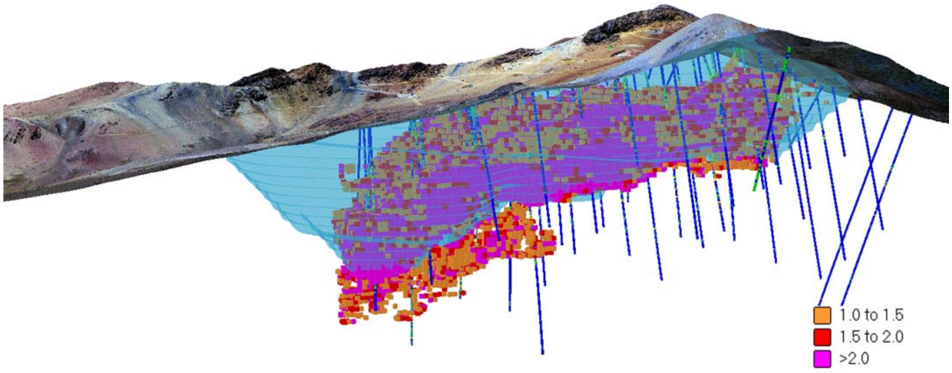
64

Building spatial models

Block models

- A block model is three-dimensional spatial representation to quantify the geology and economics of a deposit which in turn is used in mine planning



Building spatial models

Block models

- 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 blocks 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!

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67

Building spatial models

Scenario world

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

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68

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

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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

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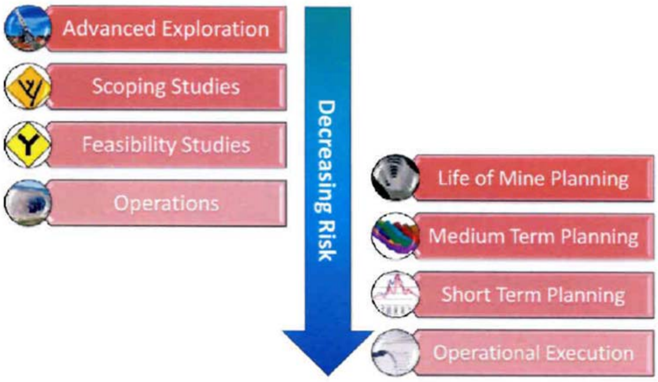
Applications of geometallurgy

Project stages



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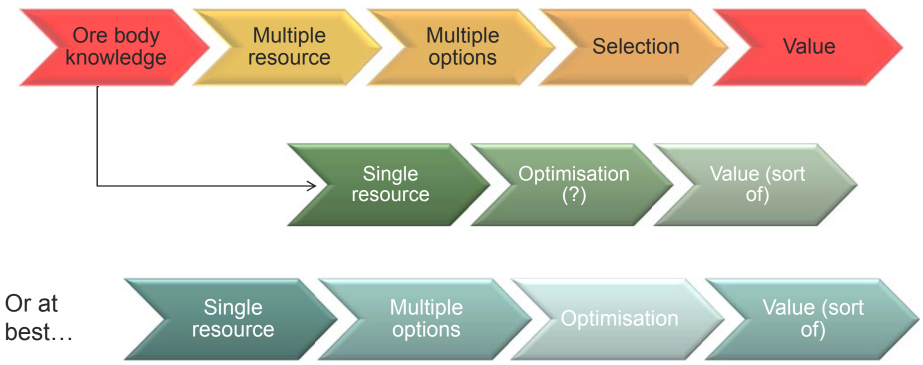
Applications of geometallurgy

The ideal approach is not what is done in the mining industry



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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.

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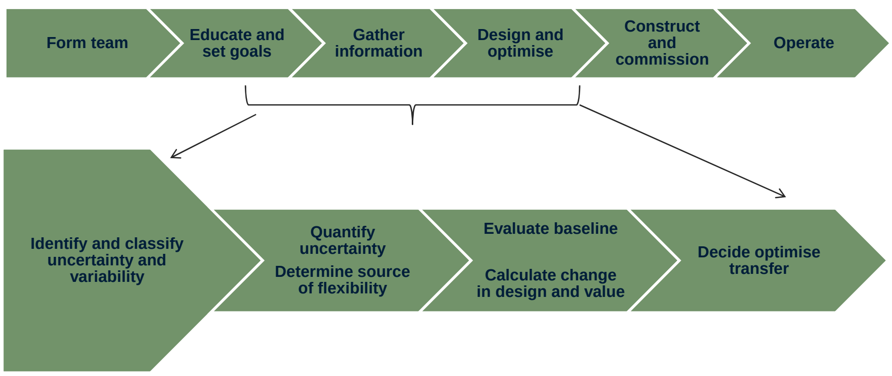
73

Applications of geometallurgy

Options thinking in projects

Mendler and Odell, 2000



74

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.

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75

Applications of geometallurgy

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)

How comfortable are you?

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76

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 oredoby 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.

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Applications of geometallurgy

What the resource model is NOT

- The truth
- Reality (it is a model)
- Free

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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

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Proactive rather than reactive

Vann and Dunham, 2007

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