The emerging study of geometallurgy – what is it and where might it go?

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Clinton Smyth (Vancouver)
November 10th 2010

Introduction

- *Geometallurgy is the study of the drivers of metallurgical response that lie in the geology and mineralogy of the rock that is exploited.*
    - *Geometallurgy is used to optimise process flow sheet design and economic return of the resource exploited*
- Why is this important?
    - It provides us a framework or methodology to go about new project development
    - Enables us to learn from existing / past operations
    - It enables us to technically optimise a new project’s economic return

The Geometallurgical Framework

- Is rooted in the geological / mineralogical domains that exist in a deposit
- Sets out to consider metallurgical parameters at an early stage of project development
- Requires spatially discrete samples of all deposit domains for characterisation by their mineralogy, grindability and metallurgy, with a view to optimal metallurgical flow sheet development
- Supports metallurgical / economic models built to forecast responses to different parameter changes
- Ideally provides data for incorporation into the mining block model to optimise mine planning and scheduling

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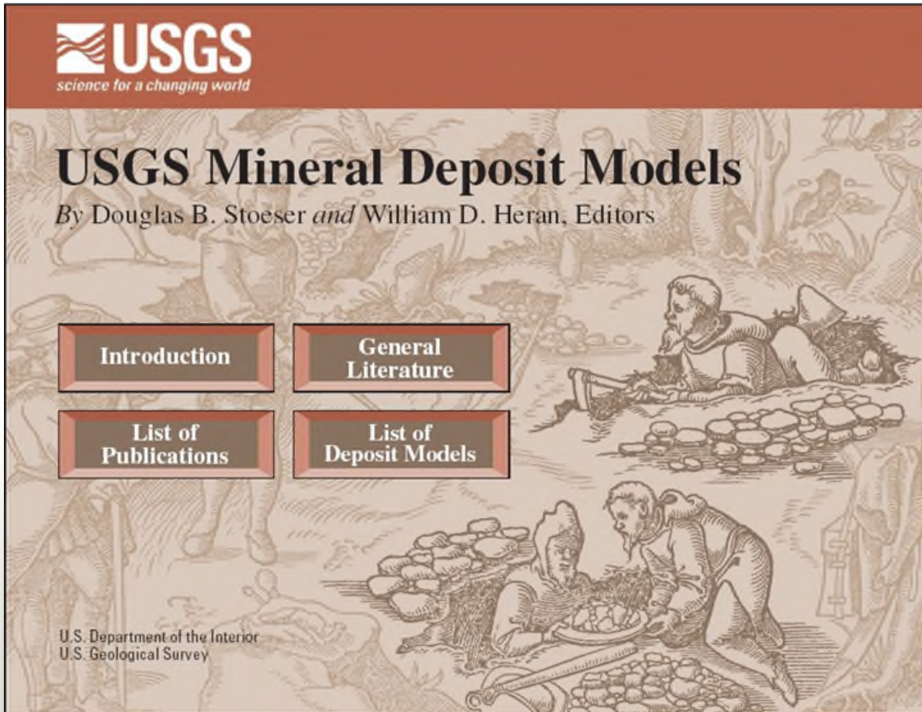
The Geometallurgical Framework: Geological / Mineralogical Domains

- One starting point is the deposit's geological model type (eg: USGS classification system)
  - Good for common deposits - not for all new discoveries



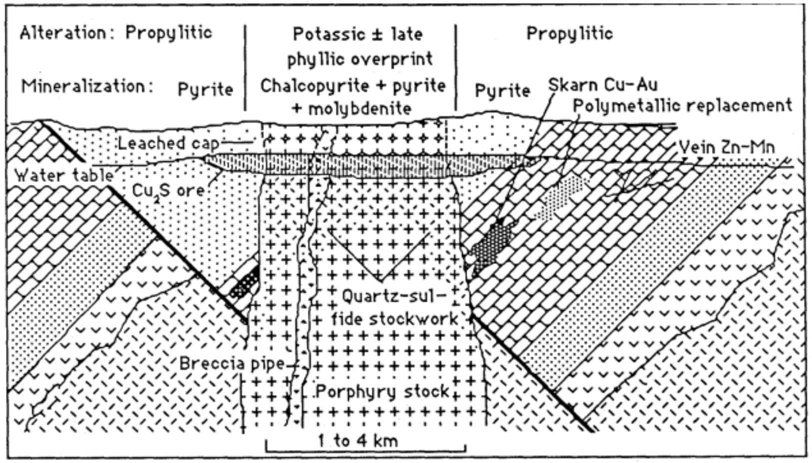


Figure 50. Cartoon cross section illustrating generalized model for porphyry Cu deposits showing relation of ore minerals, alteration zoning, supergene enrichment and associated skarn, replacement, and vein deposits.

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The Geometallurgical Framework: Geological / Mineralogical sub-domains

- One starting point is the deposit's geological model type (eg: USGS classification system)
  - Good for common deposits - not for all new discoveries
- These models were developed to aid exploration but provide a useful structure for geometallurgy and delineation of sub-domains
- The sub-domains ultimately have to be interrogated from the perspective of their metallurgical response and the key drivers to this
  - Eg a highly altered zone may have high problematic levels of clay that drive the metallurgical response

The Geometallurgical Framework: Models (1)

- What is a model?
  - A person on a catwalk showing clothes!! Hardly!!
  - “a simplified representation of a system or phenomenon, as in the sciences or economics, with any hypotheses required to describe the system or explain the phenomenon, often mathematically” – That’s better!!
- The model is built to help us understand something complex in a more simple form
- In our case our model(s) enable us to take all the information we have from characterisation and then interpret the results in some meaningful way such as resultant throughput, recovery and / or economic return

The Geometallurgical Framework: Models (2)

"… USGS studies have helped to show that the same similarites in geologic characteristics among deposits of a given type also help define the environmental signatures that develop prior to mining and the environmental signatures that develop as a result of mining and mineral processing.

The USGS has added environmental information to the mineral deposit models (termed <u>geoenvironmental mineral deposit models</u>) that summarize important environmental geology characteristics of given deposit types."

Awaiting formalisation: Geometallurgical Models

Project Chief:
Geoffrey Plumlee, USGS
Box 25046 Denver Federal Center MS 973
Denver, CO 80225-0046

The Geometallurgical Framework: Models (3)

- What model should we use in each study?
  - As many as possible must be considered; many may apply
  - May not provide specific answers, but guidelines
  - Should be evaluated for the parameters that dominantly drive metallurgical response
  - * Be alert to mineral systems where the metallurgical performance is heavily dominated by one critical parameter (eg carbonaceous material in Kuperschiefer sedimentary Cu type deposits).
  - ** Keep in mind the objective (as this drives the model(s))
    - Feasibility studies – Optimising plant design and forecasting production and project IRR
    - Mine operation – Optimising production performance by mine plan manipulation
  - Models can evolve with the project; best kept simple

The Geometallurgical Framework: Sampling the sub-domains

- All sub-domains of the probable mining deposit that are of sufficient volume to be economically important should be sampled
- Samples must be spatially discrete
- The number of samples required from each sub-domain should be relatively proportionate to the volume of each of the sub-domains
- Many samples for mineralogical characterisation; many, but less for metallurgical tests.

The Geometallurgical Framework: Mineralogical Characterisation

- Fundamental
- Systematic; modal; routine; data-based
- Routed in metallurgical considerations
- Answer the same key questions
- Eg Cu / Au porphyry
  - Cu modal, sulphide modal, gangue modal but particularly alteration minerals, Au deportment, key contaminant elements such as As
- QEMScan / MLA plus ... XRD, Au

The Geometallurgical Framework: Metallurgical Characterisation (1)

- Metallurgical flow sheet development using composite samples (built up from the sub-domain samples)
- Comminution characterisation using standard tests (at least one from each size)
  - Coarse size grinding: SPI, SMC, Bond Crushing Index, Bond Rod Mill Work Index
  - Finer size grinding: Bond Ball Mill Work Index
- Note - comminution sub-domains may be different to metallurgical sub-domains

The Geometallurgical Framework: Metallurgical Characterisation (2)

- Simple, routine, standard tests based around the expected concentration process(s)
- The tests follow logically the expected flow sheet
- The test(s) need to reflect the theorised model(s)
  - Eg kinetics of flotation
  - Eg influence of Cu modal, pyrite content and clay content on metallurgical response
  - Eg Au deportment vs cyanide recovery

Geometallurgy for Project Technical / Economic Optimisation

- Probable recovery is factored into economic and strategic considerations throughout project life
- Variable metallurgical response is calculated into project economics
- The whole deposit can be considered as a techno-economic optimisation
- Sub-domains are weighted to their relative abundance
- Should be integrated with the project feasibility mine plan for cash flow forecast and optimisation

Essential Learning from Similar Existing or Past Operations

- There are **similar** geology / mineralogy type **deposits** in the world
- Learn from these for early project strategic assessment when you have limited information about your new project
- Fast track project development using these as "models", applying past experience
- Benchmark your project against these from development through to operation
- Be alerted to alternative or new technological routes that are appropriate

How does all this help?

- Reduces risk of problems at operation
- Learn from the past – faster track to development
- Optimise cash flow
- Optimise project design
- Maximise economic return
- Build investor and financial partner confidence

Why is this geometallurgical (model) approach not widely practised now?

- It is difficult to search for models & similar deposits
- We are stuck in a traditional, compartmentalised approach:
  - We explore
  - We develop our resource base
  - We do pre-feasibility study / feasibility study with metallurgy – often in isolation from similar studies
  - Metallurgist "receives" the sample, and there is a gap in understanding between geologists and metallurgists (and a gap in language between geologists and metallurgists eg: "model" means different things to each group)

Applying Geometallurgy

- Framework and Methodology

Integrate Geology (1) and Metallurgy (2) Knowledge Bases

- Deposits (336)
- All References (496)
- Deposit Models (1)
- Period Events (13)
- Geological Zones (1)
- Metallurgical Domains (1)
- HeadGrade Tonnage (13)
- Flowsheets (1)
- Circuits (0)
- Recovery (13)
- Images (6)
- Edit Profile
- User Admin
- Edit Notes
- Matcher
- USGS Models
- Reports
- Help
- Logout

Deposits

Current Deposit: Alumbrera

+ Add new deposit

ID	Deposit Name	Alternative Names	Country	Lat	Long	Ownership
156	Alumbrera	Bajo de le Alumbrera	Argentina	27° 20' S	66° 37' W	Xstrata plc
121	Bernic Lake	Bernic Lake, Montgary, Tanco.	Canada	50° 26' N	95° 27' W	Tantalum Mining Corporation
339	Boston Gold Deposit	BN Zone Fuchsite Stickle Back Lake	Canada	67° 39' N	106° 23' W	Newmont Mining Corporation
234	Cariboo Gold Project	Barkerville Mountain area BC vein Bonanza Ledge Butts Zone Cariboo Gold Quartz mine Cow Mountain open pit Goldfinch Zone IGM Group Lowhee Mucho Oro claim Pinkerton Zone Rainbow zone Sanders zone Snap Jack Zone Upp	Canada	53° 6 ' N	53° 6' N	Barkerville Gold Mines ltd.

Applying Geometallurgy

- Framework and Methodology

Incorporate Knowledge
of Geological Models

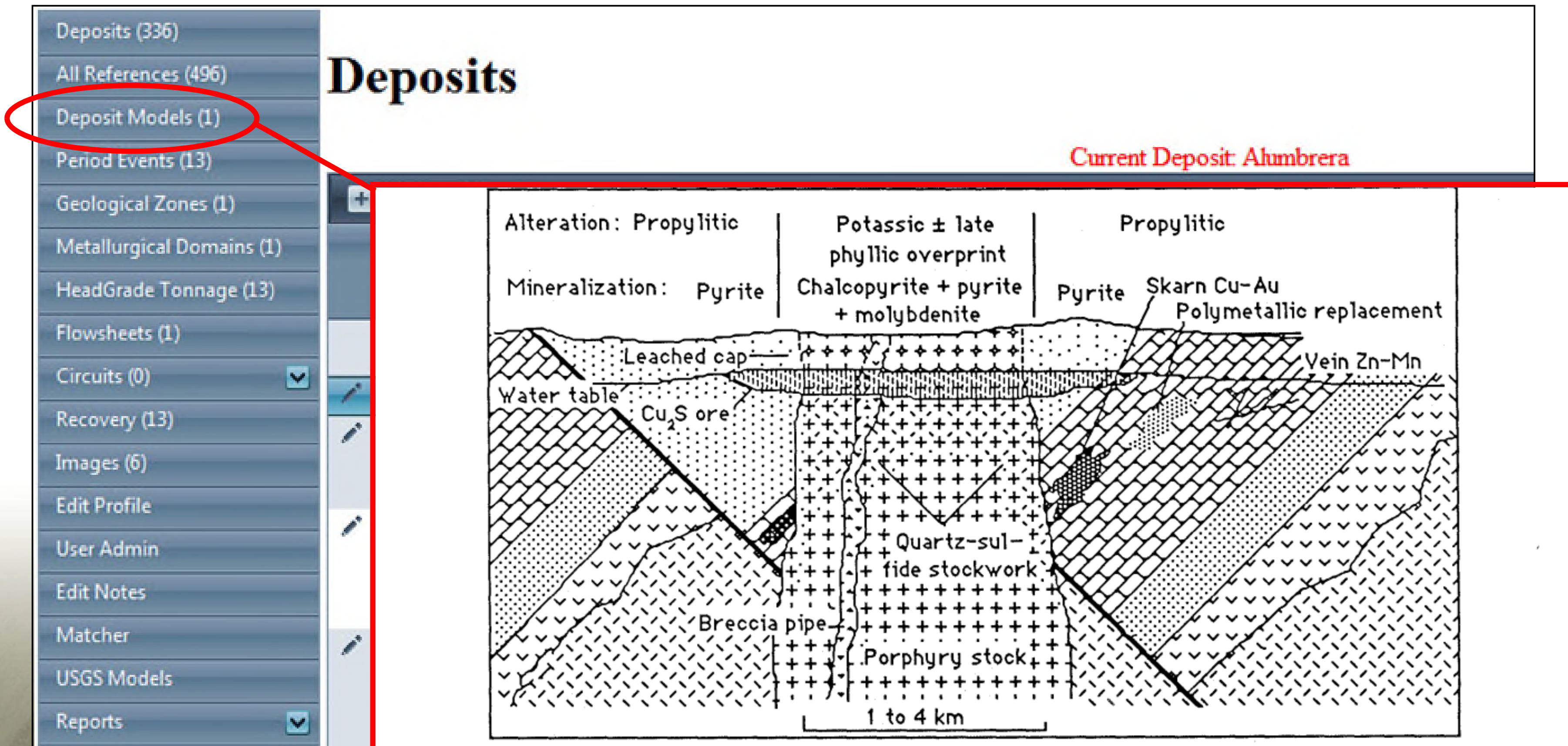
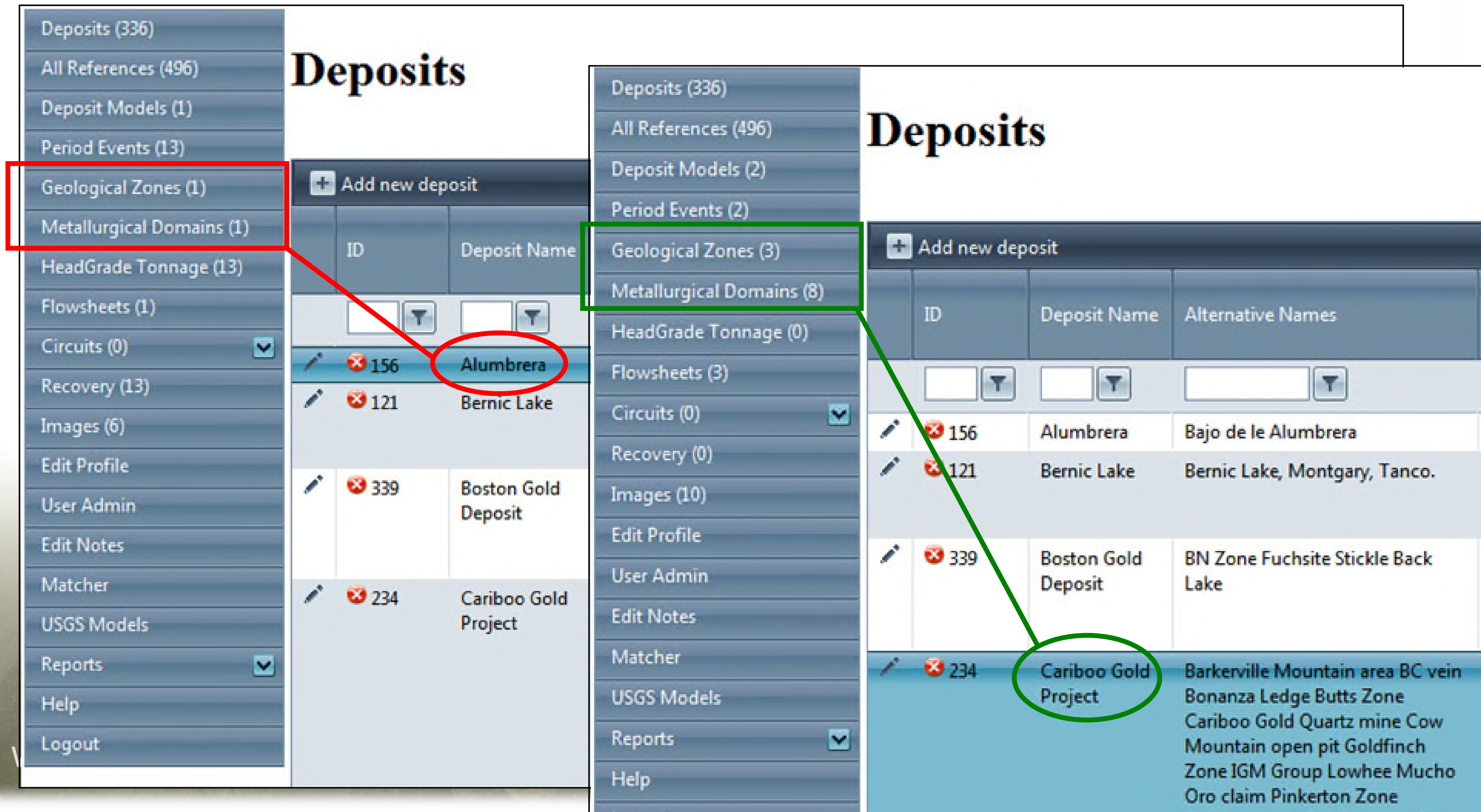


Figure 50. Cartoon cross section illustrating generalized model for porphyry Cu deposits showing relation of ore minerals, alteration zoning, supergene enrichment and associated skarn, replacement, and vein deposits.

Applying Geometallurgy

- Framework and Methodology

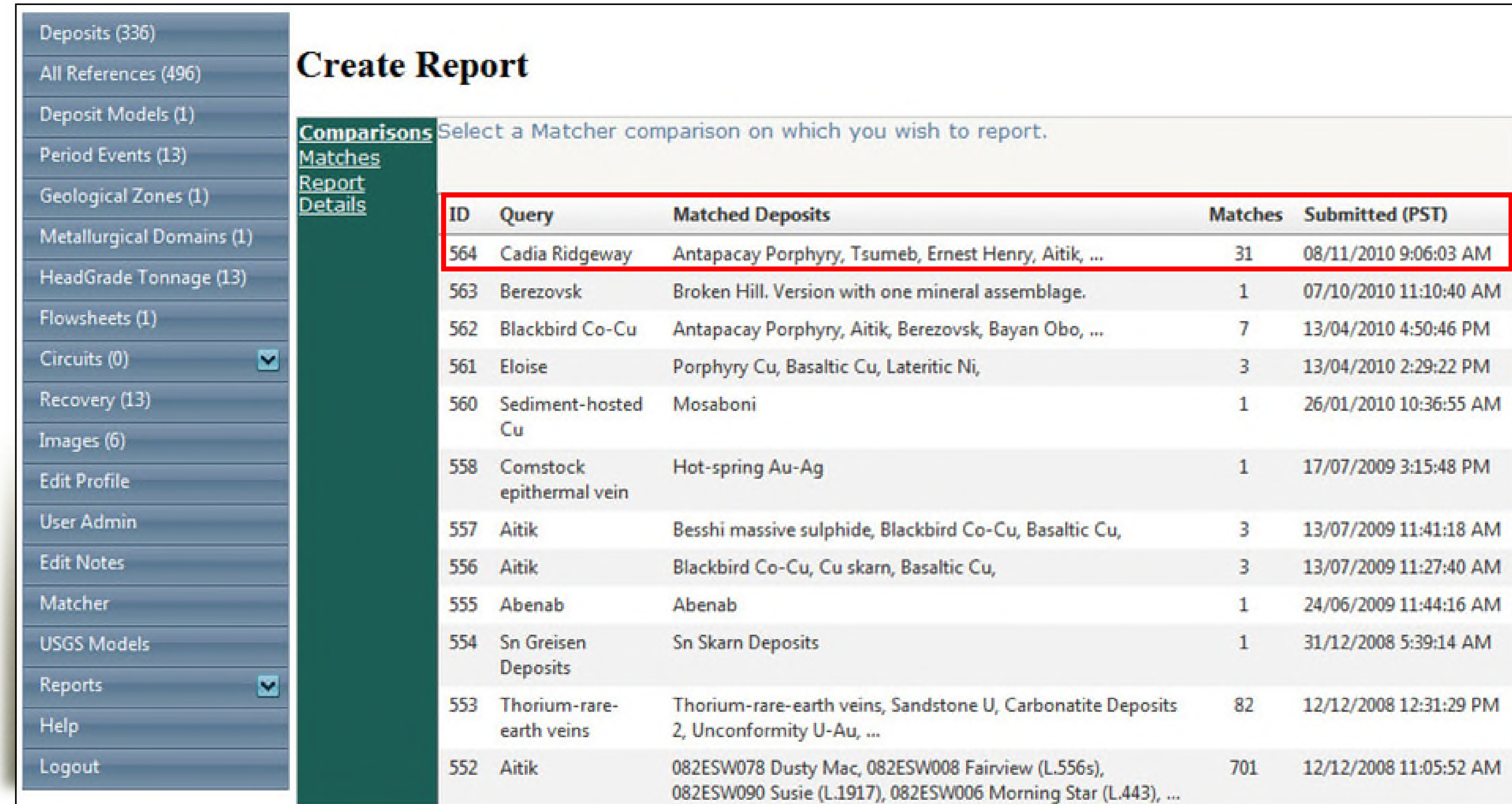
Link Geological Zones
to Metallurgical Domains



Applying Geometallurgy

- Framework and Methodology

Use Machine Intelligence to recognise similar Metallurgical domains



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Create Report

Comparisons
Matches
Report
Details

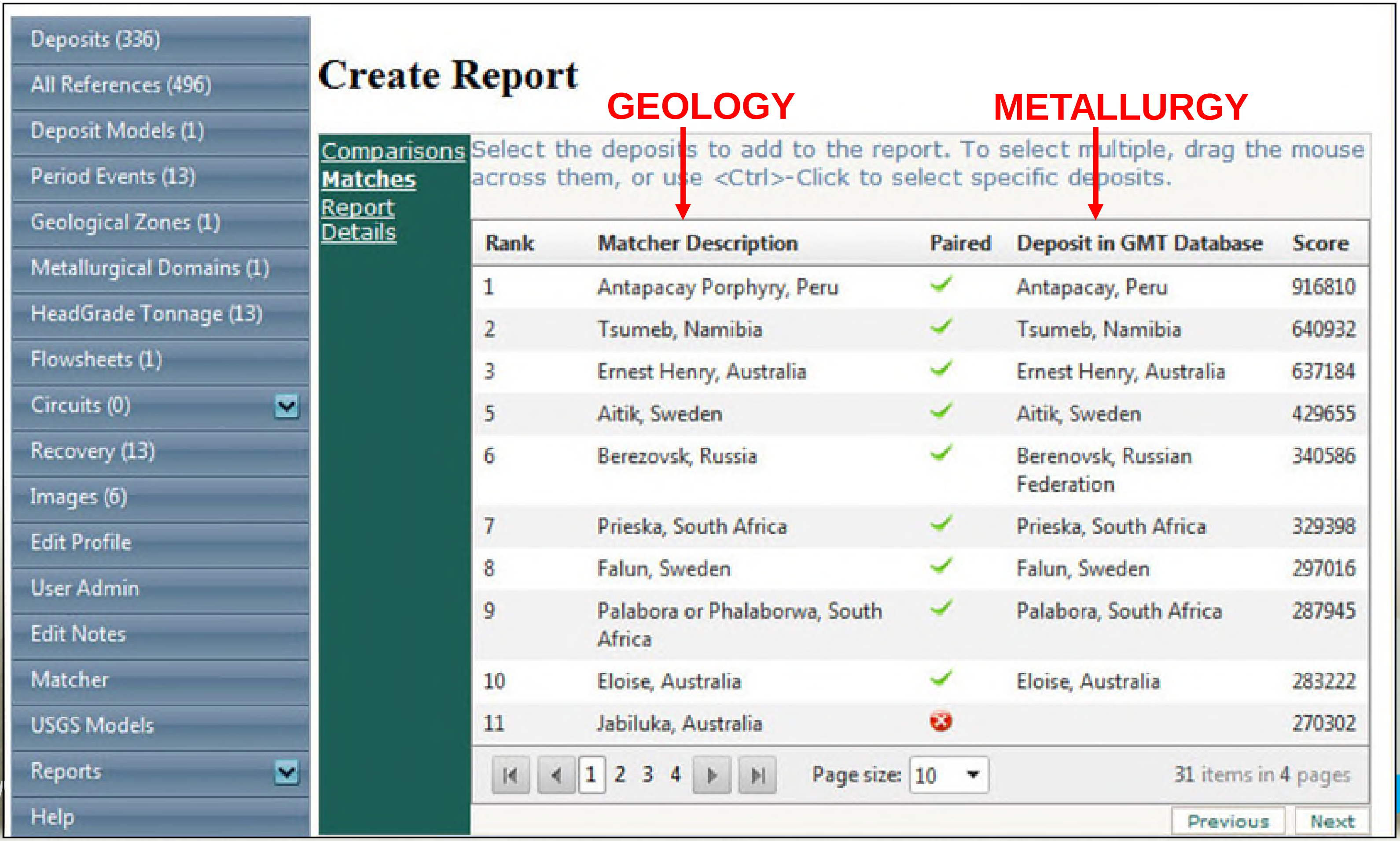
Select a Matcher comparison on which you wish to report.

ID	Query	Matched Deposits	Matches	Submitted (PST)
564	Cadia Ridgeway	Antapacay Porphyry, Tsumeb, Ernest Henry, Aitik, ...	31	08/11/2010 9:06:03 AM
563	Berezovsk	Broken Hill. Version with one mineral assemblage.	1	07/10/2010 11:10:40 AM
562	Blackbird Co-Cu	Antapacay Porphyry, Aitik, Berezovsk, Bayan Obo, ...	7	13/04/2010 4:50:46 PM
561	Eloise	Porphyry Cu, Basaltic Cu, Lateritic Ni,	3	13/04/2010 2:29:22 PM
560	Sediment-hosted Cu	Mosaboni	1	26/01/2010 10:36:55 AM
558	Comstock epithermal vein	Hot-spring Au-Ag	1	17/07/2009 3:15:48 PM
557	Aitik	Besshi massive sulphide, Blackbird Co-Cu, Basaltic Cu,	3	13/07/2009 11:41:18 AM
556	Aitik	Blackbird Co-Cu, Cu skarn, Basaltic Cu,	3	13/07/2009 11:27:40 AM
555	Abenab	Abenab	1	24/06/2009 11:44:16 AM
554	Sn Greisen Deposits	Sn Skarn Deposits	1	31/12/2008 5:39:14 AM
553	Thorium-rare-earth veins	Thorium-rare-earth veins, Sandstone U, Carbonatite Deposits 2, Unconformity U-Au, ...	82	12/12/2008 12:31:29 PM
552	Aitik	082ESW078 Dusty Mac, 082ESW008 Fairview (L.556s), 082ESW090 Susie (L.1917), 082ESW006 Morning Star (L.443), ...	701	12/12/2008 11:05:52 AM

Applying Geometallurgy

- Framework and Methodology

Leverage on Fast, Organised access to Historical Metallurgical Data



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GEOLOGY

METALLURGY

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Select the deposits to add to the report. To select multiple, drag the mouse across them, or use <Ctrl>-Click to select specific deposits.

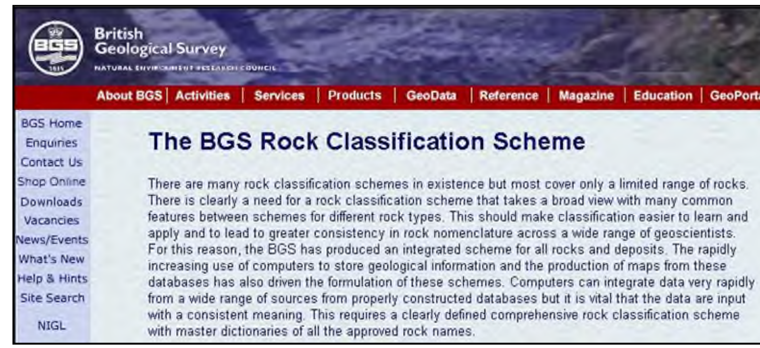
Rank	Matcher Description	Paired	Deposit in GMT Database	Score
1	Antapacay Porphyry, Peru	✓	Antapacay, Peru	916810
2	Tsumeb, Namibia	✓	Tsumeb, Namibia	640932
3	Ernest Henry, Australia	✓	Ernest Henry, Australia	637184
5	Aitik, Sweden	✓	Aitik, Sweden	429655
6	Berezovsk, Russia	✓	Berenovsk, Russian Federation	340586
7	Prieska, South Africa	✓	Prieska, South Africa	329398
8	Falun, Sweden	✓	Falun, Sweden	297016
9	Palabora or Phalaborwa, South Africa	✓	Palabora, South Africa	287945
10	Eloise, Australia	✓	Eloise, Australia	283222
11	Jabiluka, Australia	✗		270302

1 2 3 4 Page size: 10 31 items in 4 pages

Previous Next

The Geometallurgical Framework: Standardised Language Required

- In order to communicate better it is important to agree on how we talk
- The language of rocks
  - Eg what is a porphyry rock?
  - Going through change
  - See OneGeology.org
- The language of mineralogy
  - Standard nomenclature established
  - Classified by chemistry
- The language of metallurgy
  - Eg what is a fine grind?? Or too much clay??
  - Metallurgy is well behind – a need for standardisation



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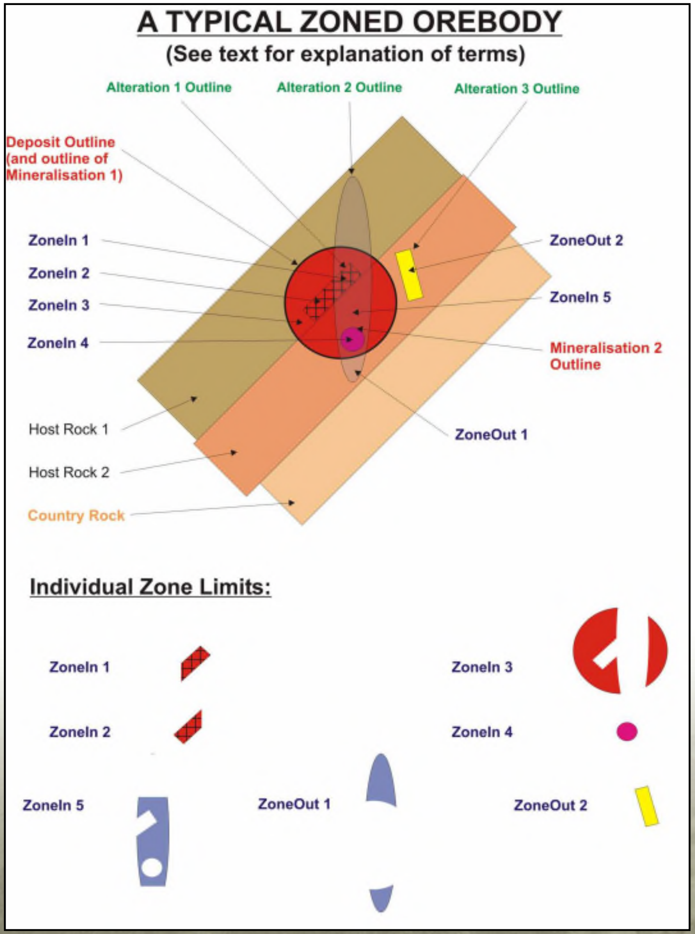
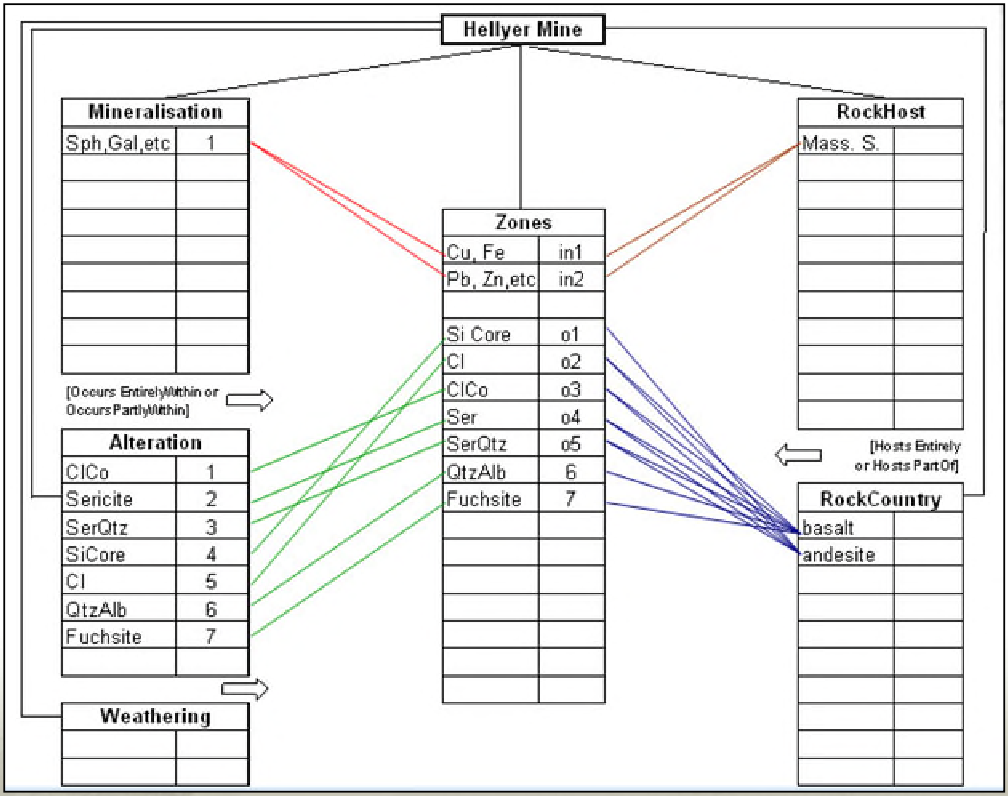
The Geometallurgical Framework: Standard Model Descriptions Required





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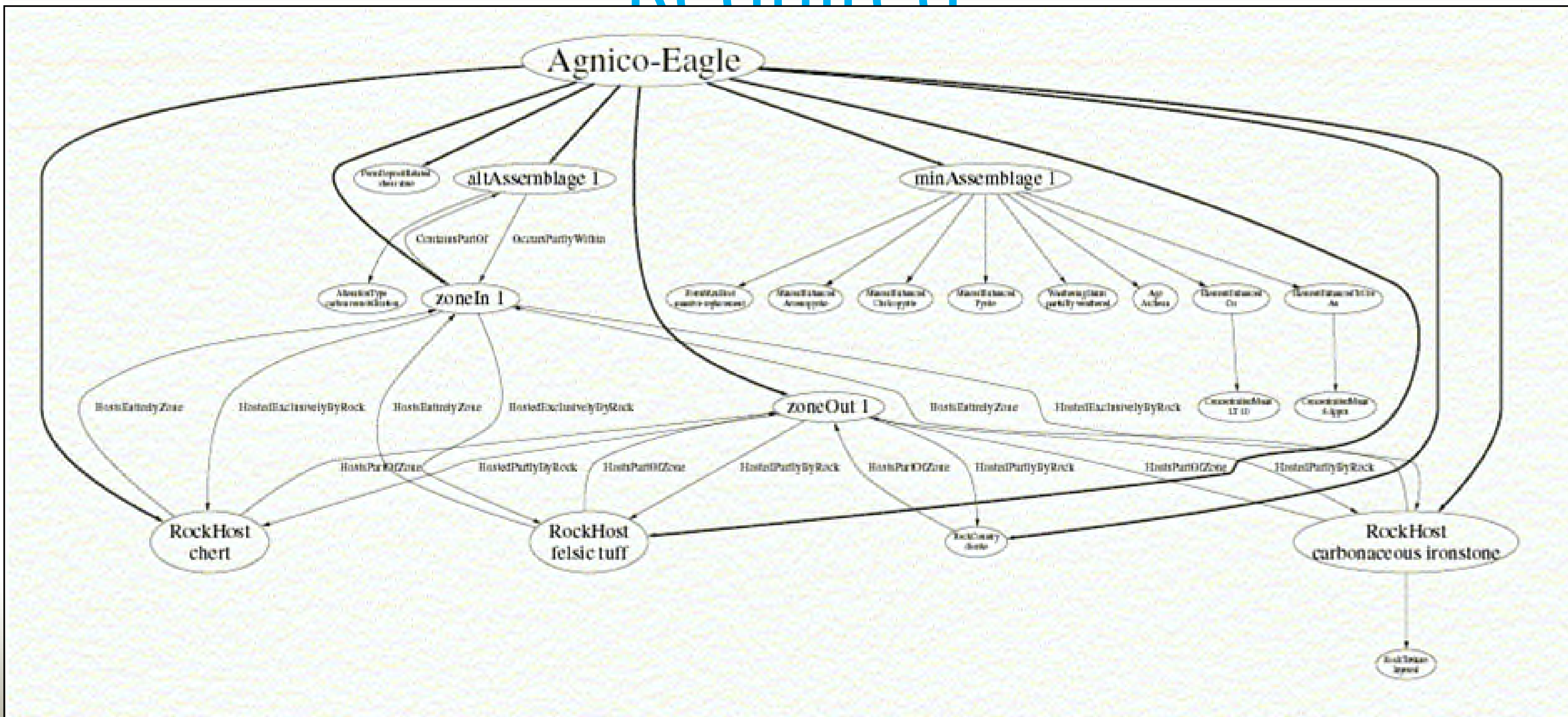
The Geometallurgical Framework: Standard Deposit Descriptions Required



So ….. the future of geometallurgy

- Studies needed
  - In field measurement(s)
  - Evolution of sub-domain definitions
  - Characterisation tools and tests
  - Geo-statistics for geometallurgical parameters
  - Mineralogical tools
  - Mineralogy – parameter(s) vs effect
  - Models
  - Integration with resource economic models
  - Integration into feasibility study methodology

So .... The future of geometallurgy

- The challenges faced
  - The ability for mining professionals to truly be able to technically communicate
  - The courses for geologists / mineralogists and metallurgists to include common courses on geology / mineralogy / metallurgy and geometallurgy
  - University courses and departments in geometallurgy (Freiberg University now has one)
  - The evolution of common language in geology (to the core logger level)
  - The development of common language in metallurgy (to the plant metallurgist level)
  - The support and embracing of geometallurgy by the mining industry and its financial partners

Conclusion

- Geometallurgy is the study of the drivers for metallurgy that lie in the geology and mineralogy of the rock that is exploited
- It enables us to economically optimise flow sheet design and project economic return and then optimise mine operation for optimised economic return
- A geometallurgical methodology is delineated
  - Based on metallurgical criteria
  - Routed in mineralogy
- Still early days and confusion with geometallurgy
- Biggest challenge faced is one of technical communication that requires changes in language, technical training
- Much opportunity for technical study
- It is possible to see a world "post-geometallurgy" where geometallurgy served to develop our holistic thinking of deposits – towards metallurgical models but in a geological sense!

Thank You