Workshop

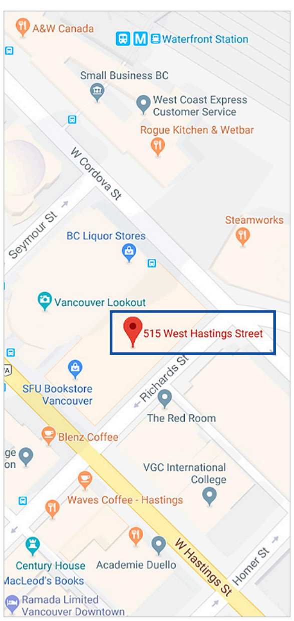
Application and Technological Developments for Ore Characterization within Geometallurgy

Date
22nd of June 2018
8:30 – 16:15

Location
Simon Fraser University Vancouver Campus (Harbour Centre)
515 W Hastings Street
Vancouver, BC V6B 5K3,
Canada

Organizers
Shaun Graham
Carl Zeiss Microscopy

Dr. Julie Hunt
Minerals Development Research Unit



A key component of developing and delivering a successful geometallurgical program is carrying out comprehensive and quantified ore characterization. This is combined with metallurgical test work to provide a geometallurgical model that is used to manage risk and enhance the profitability of the deposit.

To provide characterization of mineralogy and texture, a diverse tool box of technologies is needed. This one-day workshop will bring together experts from around the world to discuss the technological developments of this ever-broadening characterization tool box and the applications of these technologies within geometallurgy.

Agenda

8:30 – 9:00	**Julie Hunt (MDRU)** Opening Remarks
9:00 – 10:00	**Professor Alan Butcher (GTK)** How Learning For The Oil Industry Can Benefit Exploration and Mining Of Minerals
10:00 – 11:00	**Shaun Graham (Zeiss)** New Frontiers In Micro-Analysis Workflows For Improved Characterization and Ore Deposit Knowledge
11:00 – 11:20	Break
11:20 – 11:50	**Rejean Girard (ios Géoscientifiques)** Gold Deportment: From Assaying To Automated Grain Counting
11:50 – 12:20	**Peter Whittaker (AuTec)** Multi-Component Gold Geometallurgy
12:20 – 13:15	Lunch
13:15 – 14:15	**Sandra Birtel and Marius Kern (HZDR – HIF)** Predictive Geometallurgy – State Of The Art
14:15 – 14:45	**Anelda van Staden (Teck ART)** Why Geometallurgy Matters to Teck – It is in the Ethos!
14:45 – 15:00	Break
15:00 – 15:30	**Neil Banerjee (Western University)** **Lisa Van Loon (LISA CAN Analytical Solutions)** Probing Mining Industry Questions Using Synchrotron Spectroscopy
15:30 – 16:00	**Shaun Graham (Zeiss)** A New Dimension To Automated and Process Mineralogy with 3D X-ray Tomography
16:00 – 16:15	**Julie Hunt / Shaun Graham** Closing Remarks

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How Learning for the Oil Industry Can Benefit Exploration and Mining Of Minerals

Alan R Butcher
Research Professor in Geomaterials & Applied Mineralogy, Geological Survey of Finland, Espoo, Finland

It is important in this age of digital communication, more than ever, that scientists and engineers freely communicate and share their ideas, as cross-disciplinary collaboration can often lead to extraordinary developments and breakthroughs.

Take for example the oil industry, where cuttings and core are the only way to know what is beneath the ground. There is no chance of digging a trench or opening up a trial pit, as in mineral exploration and mining. Making the most of every centimeter of core, or gram of ditch cutting sample, is a key driver for innovation and development, especially when it comes to rock and mineral analysis. Nothing is left to chance, the risks are too big, and aspects such as correct stratigraphic interpretation and prediction must be as accurate as possible in order to reduce the chances of placing a well in the wrong place.

As a result, just about every possible geo-analytical technique is used to characterize the physical properties of the overburden, cap rock, reservoir, source and even the basement. All physical attributes of a rock or mineral are exploited to further understand what is present and how it will respond at reservoir conditions – these include: mineralogy, texture, 3-D grain network, pore structure, rock density, magnetic susceptibility, radioactivity, conductivity, density, brittleness, and response to NIR, X-ray and electron beams, to name a few.

In mining, we face similar but also different challenges. Even though airborne or ground geophysical surveys, observations and interpretations are typically key to the initial target selection, everything has to ultimately be ground-truthed. Potential targets still need to be drilled to prove the presence of a potential ore-rich interval, as perhaps indicated by the physics. But once we have hit the zone of interest, do we make the most of our core? Is every length of core that is pulled from the ground fully digitally scanned before it is cut, split or sawn in half and quartered? Do we always use downhole petrophysics to see what the rock structure looks like beyond the immediate vicinity of the borehole? Probably not, mainly because the budgets and risk factors in mining are not on the same scale as the oil industry. But accepting this, what can we learn from each other?

This talk will briefly review some best practices from the oil industry which can be translated directly into the mining and exploration world with great effect. The concept of digital rock analysis, whereby a digital rendition of a real sample is used to visualize and model rock properties, is an excellent potential cross-over concept for mining, now widely used in the petroleum world. By creating a 3-D version of a core, based on reality and not a model, it is now possible to perform virtual experiments and observations without damaging the original.

New Frontier in Micro-Analysis Workflows for Improving Characterization and Ore Deposit Knowledge

Shaun D Graham
Mining & Geoscience Applications Development, Carl Zeiss Microscopy, Cambridge, UK.

For over 25 years, automated mineralogy on a SEM-EDS platform has been the workhorse to provide quantitative mineralogy characterization to improve ore deposit knowledge. Despite its success, technological and methodological developments in the EDX and elemental quantification have been limited until recent times. The development of Mineralogic now combines standards based EDS calibrations, quantitative chemical analysis, mineral classification on measured chemical compositions and textural analysis into an automated mineralogy package. As such, new applications are now being addressed as a result of these technological breakthroughs.

Whilst the above-described developments have improved SEM-EDS based automated quantitative mineralogy analysis, the analysis is still tied to the capabilities and limitations of EDS detectors. This is an issue for characterization of "hi-tech" ores/commodities containing Co, Li, REEs in low concentrations or in challenging mineralogical suites. This is a critical gap that needs to be bridged to provide the necessary microanalysis tools for mineralogical characterization and to generate the detailed ore deposit knowledge required to successfully and economically recover the valuable ore.

In this talk, we will present workflows and capabilities built around a central automated mineralogy capability and provide views towards the future analytical capabilities. This will include the applications of X-ray Microscopy to perform 3D micro-drill scanning to identify regions of interest that can then be sectioned and placed for automated mineralogy analysis in the SEM. We will present the new core abilities of automated mineralogy in chemical, mineralogy and textural understanding of these samples. We will then focus on a range of additional correlative micro-analysis capabilities such as WDS, RAMAN, HIM-SIMs, LA-ICP-MS and also machine learning solutions that can be utilized.

These techniques and their compatibility are essential in providing the correct level of mineralogical, chemical and textural information to ensure that extraction of these commodities is possible. Successful and thorough ore characterization, building up ore body knowledge and using this to create robust geometallurgical domains for these deposits, will require this detailed mineralogical characterization and enable technologies and workflows.

Réjean Girard
ios Géoscientifiques, Chicoutimi, Quebec, Canada

Every year, the mining industry loses approximately 300 tons of gold in its tailings. But how much of this gold is refractory in sulphides or arsenided, how much is locked in silicates due to deficient grinding and how much is free but failed to be recovered?

Measuring the deportment of gold in tails is difficult due to its very low abundance, small grain size and nugget distribution. And difficult therefore means slow and costly laboratory procedures, which cannot be embedded in a routine procedure to control mill efficiency and correct issues in a timely manner.

The talk will present how the gold deportment can be efficiently measured and how new concentration procedures, automated optical microscopy coupled with correlative SEM-based automated grain counting plus LA-ICP-MS has been integrated to offer a fast and cost effective solution. Examples of integration in gold mines from the Abitibi will be presented.

Multi-Component Gold Geometallurgy

Peter J Whittaker
AuTec Ltd., Vancouver, British Columbia, Canada

Understanding how different lithologies within a new or existing ore deposit respond to metal extraction is key to determining the economic viability of a new deposit or zone. Gold deposits require a rigorous evaluation of metallurgical performance on a lithological or geometallurgical basis. Provision of mineral, geochemical and initial metallurgical information at advanced exploration drilling stages is essential to identify potentially problematic zones before major processing commitments are made. This can be applied to Carlin Trend and South American high sulfidation type deposits amongst others.

The approach for new and existing deposits begins with definition of new zones and representative sampling by project geologists. Zone definition within a deposit is based on lithological, structural, alteration and geochemical criteria. A range of test work is carried out on each zone to provide a comparison of metallurgical behavior and to define expected gold recoveries. Initial evaluation includes assays and X-ray diffraction based quantitative mineralogy, sometimes augmented by scanning electron microscope based mineralogy, to help direct additional metallurgical testing. A multi-component metallurgical test work program is designed and can include acid and alkaline pressure oxidation (POX), bench top roasting, magnetic separation and flotation on both composite and variability samples.

Predictive Geometallurgy – State of The Art

Sandra Birtel, Marius Kern, Philipp Büttner, Kai Bachmann, Max Frenzel, Jens Gutzmer
Helmholtz- Zentrum Dresden Rossendorf, Helmholtz Institute Freiberg for Resource Technology, Germany

SEM-based automated image analysis is well established as a key tool in geometallurgical assessments, as it provides quantitative data on mineralogy and microstructure. It is also widely used in the mining industry to improve recoveries and to monitor process efficiency of processing plants. More recently, automated mineralogy has been also used to assess the presence and distribution of possible by-product or even penalty constituents. The approach at the Helmholtz Institute Freiberg of Resource Technology goes beyond these current applications: data from SEM-based automated analyses such as MLA in combination with complementary analytical methods (such as XRD and EPMA) is statistically assessed in order to predict the behavior of material during beneficiation. The purpose of this approach is to confidently reduce technical risk of raw materials projects whilst also reducing the need for empirical test work.

This study will exemplify this approach with four very different case studies, including (1) on the recovery of Sn from a historic flotation tailings storage facility; (2) on by-product recovery from a chromite ore deposit, (3) on simulating sensor-based presorting; and (4) by-product recovery from a polymetallic base metal ore. All studies were performed by interdisciplinary teams including resource characterization, minerals processing and statistical modelling.

Predictive Geometallurgy – State of The Art continued

1) A predictive geometallurgical model of a tailings storage facility in the Erzgebirge (Germany) was created based the assessment and weighting of grade, modal mineralogy, liberation, grain size and flotation behavior of tailings intersected by a series of drill cores. All data was geo-referenced and combined to construct a 3D model illustrating the amount of cassiterite–bound tin that can realistically be recovered from the tailing. Results of this study illustrate the importance of combining different tangible parameters to assess the recoverable value that remains in industrial residues – such as flotation tailings.

2) A predictive geometallurgical model was created for an ore body comprising several stratiform chromitite seams in the Bushveld Complex (South Africa). The focus of this study was the assessment of the potential for PGE recovery as a by-product. Samples were collected from a series of drill core intersections of the different chromitite seams. More than 100 individual samples were studied in detail. Results were clustered, focusing on parameters relevant for beneficiation of PGE, such as PGE mineralogy, mineral association, grain sizes etc. These predictions were validated by selected metallurgical tests. Compositional clusters were then related back to well-known geological features. This integration of data served to define geometallurgical domains.

3) Assessing the success of sensor-based presorting currently requires time-consuming and expensive empirical test work. Yet, the prospects of success can be simulated with automated mineralogy data. This is illustrated using the example of a mineralogically and texturally complex skarn ore from the Hämmerlein Sn-In-Zn deposit, Germany. Cassiterite is the most important ore mineral and Sn is the major value constituent in the polymetallic skarn ore. The presence and abundance of cassiterite itself (< 4 Vol. %) is not a suitable target for sensor-based sorting. Yet, it appears intimately associated with a cogenetic chlorite-fluorite-sulfide assemblage. Parameters from MLA datasets, such as modal mineralogy and mineral density distribution were used to simulate the prospects of sensor-based sorting using different sensors. The results illustrate that the abundance of rock-forming chlorite and/or the density anomalies may well be used as proxies for the abundance of cassiterite.

4) The mineralogical deportment of Indium in mineralogically complex base metal sulphide ores from a mine in the Iberian pyrite belt was defined in order to constrain the potential to realize credits from this valuable by-product. Different to the previous case study, Indium does deport mostly into major ore-forming sulphides – and rarely forms its own ore minerals. The study is based on a combination of data from assays and MLA, data for geological and processing samples. In addition, an extensive set of mineral chemical data was acquired by EPMA to constrain the In deportment. Statistical regularities in the deportment of In are then used to predict In deportment from assay data alone. This predictive assessment includes statistical uncertainties, achievable recoveries and payable concentrate compositions. This, in turn, may be used in future mine planning.

Key innovations introduced by these three case studies are of general applicability to other metals and ore types. They clearly illustrate the value of conducting predictive geometallurgical assessments already during the latter stages of exploration in a process that will benefit from regular follow-up during the phase of active exploitation.

Why Geometallurgy Matters to Teck – It is in the Ethos!

Anelda van Staden
Teck – Applied Research and Technology, Trail, Canada

Teck has sponsored and actively participated in collaborative research programs focused on GeoMetallurgy since 2005. Process mineralogy has played an integral role in these efforts and added value at all levels of the mine life cycle.

One example is the continual innovation in the process mineralogical characterization of orebodies within the Red Dog district. The original simplistic 3-D geological model of the Main Pit and Aqqaluk orebody were updated with models for zinc, lead and silver recovery, as well as mill throughput. This was only possible through an extensive and collaborative GeoMetallurgical program performed within the previous decade.

In addition, diagnostic mineralogy has improved our understanding of processing difficulties experienced by feed blends from the Red Dog deposits, with analysis of terminal streams continuing to this day.

The significant GeoMetallurgical challenges posed by the complex paragenesis and overprinting relationships that characterize mineralization in the Red Dog deposits necessitates innovative approaches to better define the mineralogical and metallurgical variability.

This talk will present how process mineralogy and various analytical methods have been used to unlock the value of these new deposits and improve our understanding of metallurgical challenges posed by feed blends.

Probing Mining Industry Question Using Synchrotron Spectroscopy

Neil Banerjee
Western University, Ontario, Canada

Lisa Van Loon
LISA CAN Analytical Solutions Inc

Synchrotron spectroscopy applied to life of mine (mineral processing, exploration, and remediation) challenges canaddress industry relevant questions and provide rapid solutions that add significant value by using a robust andhigh-resolution analytical technique. But the barrier to adoption of these techniques by the broader mining community is significant. Through a unique collaboration between academia, industry, and synchrotrons we are tackling this problem head on to develop techniques for the mining industry.

Synchrotron micro X-ray fluorescence (uXRF) provides rapid and cost-effective micron-scale trace element analysis and mapping of ore minerals at ppm levels. Speciation of trace elements important for understanding deportment, metal mobility, and the presence of deleterious phases can be probed using X-ray absorption near-edge structure (XANES) spectroscopy. uXRF mapping and XANES analysis of pyrite grains from gold camps across Canada have revealed key indicators of mineral liberation, mineralization history, and novel exploration vectors. Gold in these deposits is present both as free and/or "invisible" gold, bound in the pyrite crystal lattice. The high flux and energy of a synchrotron allows for *in situ* and non-destructive detection of invisible gold by uXRF, and probes its nature using XANES spectroscopy. New fast-scan boron K-edge XANES spectroscopy provides a novel, direct, and rapid uranium exploration vector. XANES directly identifies the speciation and the proportions of trigonally-coordinated (BO3 moieties) and tetrahedrally-coordinated (BO4 moieties) boron in complex mineralogical mixtures in whole rock samples and suggests a link between boron coordination chemistry with uranium mineralization.

It is important to determine which minerals are present in any tailings management facility for regulatory compliance and how they evolve over time. XANES spectroscopy is an excellent tool for determining element speciation. The oxidation-reduction of deleterious-element bearing compounds (e.g., As, Se, Mo, Cr, etc.) can be monitored and effective management practices implemented to ensure long-term capture.

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A New Dimension to Automated and Process Mineralogy with 3D X-Ray Tomography

Shaun D Graham
Carl Zeiss Microscopy, Raw Materials Laboratory, Cambridge, UK

Process mineralogy studies have typically been carried out using 2D SEM-EDS automated analysis. These solutions have become a key part of modern day mining operations and process mineralogy studies. Whilst the data from these techniques is invaluable, the application of these solutions is done accepting a range of limitations and assumptions. The application of 3D data can overcome some of these limitations such a stereological artefact, sampling bias and statistical representivity.

Recent developments in understanding and applying 3D tomography has opened up new areas of applications, the most interesting of these is its applications in with the mining value chain, and most specifically within process mineralogy. There are clear case studied examples where the application of 3D data can be applied with clear advantages over 2D techniques.

This talk with outline the technological capabilities of the X-Ray Microscope and how it can be used to generate process mineralogy specific data, such as bulk mineralogy, liberation and free surface area. It will focus on key application areas where this technology can provide valuable data and pay particular attention to how it is currently used in understanding tailings and acid mine drainage.