The Difficult Mineral Processing Issues with Processing High Clay Ores

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AUSTRALIA

COM 2013

CONFERENCE OF METALLURGISTS

Hosted by MS&T13

October 27-31, 2013 | Montreal, Canada
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> ACKNOWLEDGEMENTS
This document is a dynamic record of the knowledge and experience of personnel at Mineral Engineering Technical Services. As such it has been built upon over the years and is a collaborative effort by all those involved. We are thankful for the material supplied by and referenced from various equipment manufacturers, vendors, industry research and project partners.
Key Attributes

Pragmatic, efficient, complete engineering through quality, personalised & exceptional service delivery

> Working globally since 1988
> Dynamic and innovative niche consultancy
> Dedicated team providing customised service
> Specialist in Mineral Processing & Engineering Projects
> Unique solution finder
> Clays cause inherent materials handling with mineral processing and difficulties because of their wet sticky nature

> Clays are typically < 2 microns

> They have high surface areas and reactivity (swelling and adsorbing power)

> There are many clay mineral groups-identification

> Mostly weathering products are above the water table or due to argillic alteration

> The Mineral Processing issues are problematic
The Problem With High Clay Ores

- Materials handling-bins & stockpiles
- Crushing & screening
- Heap leaching-percolation
- Milling & classification
- Leaching
- Pumping
- Flotation
- Thickening & filtering
- Tailings drainage
## Conventional Mineralogical Techniques

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Applications</th>
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</thead>
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<tr>
<td>Gravity concentration</td>
<td>Concentration of metal and metal-bearing minerals</td>
</tr>
<tr>
<td>Optical microscopy</td>
<td>Identify metal and other minerals and their mineralogy characteristics</td>
</tr>
<tr>
<td>Cyanide leaching</td>
<td>Determination of the amount of recoverable by cyanidation</td>
</tr>
<tr>
<td>Acid diagnostic leaching</td>
<td>Determination of metal associated with carbonates, sulfides and silicates</td>
</tr>
<tr>
<td>X-ray diffraction</td>
<td>Determination of metal and other minerals and their mineralogy characteristics which include texture, crystallographic and particle size</td>
</tr>
</tbody>
</table>
# Advanced Mineralogical Techniques

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Applications</th>
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<tbody>
<tr>
<td>Scanning electron microscopy (SEM) (qualitative versus quantitative image analysis)</td>
<td>Mineral identification, liberation, surface morphological study and modal analysis</td>
</tr>
<tr>
<td>QEMSCAN with Mineral Liberation Analysis (MLA)</td>
<td></td>
</tr>
<tr>
<td>Secondary ion mass spectrometry (SIMS)</td>
<td>Quantification and mapping of element</td>
</tr>
<tr>
<td>Particle-induced x-ray emission (PIXE)</td>
<td></td>
</tr>
<tr>
<td>Laser ablation microprobe inductively coupled plasma mass spectroscopy (LAM-ICP-MS)</td>
<td></td>
</tr>
<tr>
<td>Time-of-flight laser ion mass spectroscopy (TOF-LIMS)</td>
<td>Quantification of adsorbed metal on the surface of carbonaceous matters and other minerals Determination of inorganic surface composition</td>
</tr>
</tbody>
</table>
Optical Microscopy is usually performed by a mineralogist or geologist—thin section & block.

Thin sections:

A: association between various copper sulfide minerals
   bornite: Cu$_6$FeS$_4$, digenite: Cu$_9$S$_5$, covellite: CuS within malachite: Cu$_2$CO$_3$(OH)$_2$

B: intimate association between bornite and digenite
Scanning Electron Microscopy

> an imaging technique using backscattered electrons to identify mineral phases in a ore / rock sample
  > need to be coupled with energy dispersive spectrometry (EDS) for definitive identification
> image contrast used to identify the ore minerals and their associations with other minerals
  > Higher the atomic number, the brighter the image

Back-scattered electron image (BS)

silver mineral acanthite $\text{Ag}_2\text{S}$ (bright)
in a copper mineral malachite $\text{Cu}_2\text{CO}_3(\text{OH})_2$ (dark)
Energy Dispersive Spectrometry (EDS) provides identification of elements in mineral phase down to a small (~5 mm) area.

olivine: \((\text{Mg}_{0.91}\text{Fe}_{0.09})_2\text{SiO}_4\)

titanate: \((\text{Mg}_{0.15}\text{Fe}_{0.82}\text{Mn}_{0.03})\text{TiO}_3\)
Small regions of individual ore minerals (2-5 mm) can be analysed to determine metal concentration down to ppm levels.

SEM contrast in BS image with EDS used to identify each possible mineral prior to trace analysis by electron microscope.

Analysis of Quartz vein gold by SEM – Electron Microphobe Analysis

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Au (ppm)</th>
<th>Ag (ppm)</th>
<th>As (ppm)</th>
<th>Cu (ppm)</th>
<th>Pb (ppm)</th>
<th>Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.42</td>
<td>96.7</td>
<td>187</td>
<td>43</td>
<td>89</td>
<td>227</td>
</tr>
<tr>
<td>2</td>
<td>13.1</td>
<td>93.7</td>
<td>635</td>
<td>46</td>
<td>46</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>14.6</td>
<td>230</td>
<td>903</td>
<td>368</td>
<td>330</td>
<td>1050</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>404</td>
<td>178</td>
<td>702</td>
<td>458</td>
<td>1350</td>
</tr>
<tr>
<td>5</td>
<td>34.2</td>
<td>314</td>
<td>128</td>
<td>372</td>
<td>2290</td>
<td>4480</td>
</tr>
</tbody>
</table>

Mineralogical investigations of this type are rare – objective is to determine which ore minerals / metals are worth targeting via upgrade

- compliment information with head assay
This technique is quite a quick, reliable, low cost for semi-quantitative analysis of rock/ore samples

- sample is (usually) pulverized / finely ground (typically 10g)
- identification of phases achieved by pattern comparison down to ~2wt%

12 different mineral phases identified including:

- Chalcopryite
- Pyrite
- Sphalerite
- Quartz
QEMSCAN – A Technology for Rapid Mineralogical Analysis

> Third generation of automated mineral analysis system that began with the QEM*SEM at CSIRO

> The system consists of:
  – A scanning electron microscope
  – Four X-ray detectors
  – A software package based on procedures developed by CSIRO

> Capable of identifying ore- and rock-forming minerals in milliseconds
  – A scanning electron microscope
  – Four X-ray detectors
  – A software package based on procedures developed by CSIRO
Analysis Mode

- Bulk mineralogical analysis
- Particle mineralogical analysis
- Specific mineral search
- Point Scan
- Field Scan

Gold associations by TSM analysis

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Mass fraction (% w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>43.3</td>
</tr>
<tr>
<td>Fe Mg carbonates</td>
<td>26</td>
</tr>
<tr>
<td>Dolomite</td>
<td>9</td>
</tr>
<tr>
<td>Al silicates</td>
<td>15.6</td>
</tr>
<tr>
<td>Fe sulphides</td>
<td>3.5</td>
</tr>
<tr>
<td>Total</td>
<td>96.8</td>
</tr>
</tbody>
</table>

Ore mineralogy defined by QEMSCAN

Liberation by QEMSCAN
QEMSCAN – The Advantages

> To access the value of exploration discoveries
> As an aid to design metallurgical processes
> To improve understanding of ores and ore concentrates ➔ increasing production yields

automatic and rapid (unbiased) mineralogical analysis

Source: im-mining.com
Identification of Clay Minerals

- The Kaolin Serpentine Group
  - Kaolinite, dickite, nacrite and halloysite
- Serpentite Group
  - Chrysotile, lizardite, berthierine
- Talc Pyrophyllite Group
  - Pyrophyllite
- Mica Group
  - Muscovite, paragonite, roscoelite, caladonite, illite, phengite, serecite, biotite, phlogopite
- Smectite Vermiculite Group
  - Montmorillonite, beidellite, nontronite, saponite, stevensite, vermiculite
- Chlorite Group
  - Chlorite, clinichlore, chamosite, nimite, pennantite
- Mixed layer minerals
  - Sepiolite-Palygorskite/Attapulgite
  - Allophane and Imogolite
The Weathering Profile & Significance

> Clay minerals exist in the areas above the water table but can in some instances exist below it.

> The reaction of feldspars and water to form kaolinite involves the exchange of cations and produces a clay mineral.

> This makes it difficult to clearly define the zone of oxidation and therefore selectively mine these zones. Even mining fresh ore there are occasional patches of weathered clay ore within the sulphide zone.

> Must recognise and test zones at the development stage
Argillic Alteration In Ores

> Hydrothermal alteration results from the interaction of hot waters with rocks to form clay minerals.

> This is not uncommon in Epithermal deposits and results in clays persisting at depths which would not be expected.

> The phenomena of hard quartz rock with interspersed clay (5 to 15% clay) as a result of hydrothermal fluids is quite deceptive with regards to how the rock will process.
Clay Impact on Metallurgical Testwork

> Warning
  - Don’t dry clay ores or you will change the characteristics-Murrin Murrin example

> Keep some samples undried

![Viscosity Limits Diagram](ViscosityLimitsDiagram.png)
> Bypass facilities so that simply passing through the jaw crusher and into a passive stockpile can be fed to a ball mill using a front end loader, being a solution.

> Secondary crushing and screening may not be possible particularly if the ore is wet and sticky. Cone crushers bridge and screens become blinded.

> Putting clay ores into bins or stockpile with reclaim tunnels can be a disaster. They simply don’t work. Feeding direct into SAG mills is a much better option if this suits the process.

> Scrubbers ahead of crushing
Flow In Bins and Hoppers

> Funnel flow
  — Most existing bins are funnel flow
  — Size distribution of discharge depends on flow balance in the bin (charging or discharging)

> Mass Flow
  — All material in bin in motion
  — Material is remixed

> Expanded Flow
  — Combination of mass flow hopper below a funnel flow bin
> Flow problems in bins with clay ores

- Arching
  - No flow condition
  - Cause: bridging of material over opening

- Piping or rat holing
  - Restricted flow condition
  - Flow is limited to vertical channel above the discharge opening
  - Reduces bin’s effective capacity
Cannot stockpile clay ores - set go hard
Milling & Classification

> At the Kurara gold project the ore was so viscous it would not flow out of the mill even with lower densities.

> Also cyclone efficiency is negatively affected resulting in a less sharp separation. Clays affect the grinding efficiency necessitating operating the mill with a lower density to flush the clay out of the mill.

> The use of viscosity modifiers or caustic soda rather than lime will mitigate these effects.

Source: METS Library
Heap Leaching

> High clay ores require agglomeration with cement in an agglomeration drum and time to cure before stacking.

> If agglomeration is not used the percolation will be very low and effective recovery from the heap very low. The cement addition rate required is critical and can affect the economics of the process.
Gold CIP

- Stepped tanks- tanks overflow- insufficient head

- Extremely high viscosity slurries won't agitate and solids separate from water on the surface. Tanks overflow.

- Slurry like porridge- limit % of clay feed as a constraint

- Viscosity modifiers- Freevis- cost involved- Boddington

- Use of caustic not lime

Source: METS Library
The mineral sands industry uses hydrosizers up front to remove clays from the mineral sands feed. Clays negatively impact on the separation process using spirals.

 Beenup
> The original Windimurra beneficiation plant had a cyclone deslime at 10 microns to remove the clay from the ground ore.

> The removal off the clays improved the magnetic separation of the ore.

> The original Mt Tom price DMS plant suffered from clay in the feed

> Marra Mamba goethite/limonite ores can be sticky and difficult to handle

Source: METS Library
Dense media separation (DMS) plants fail to achieve a separation if clay is present in the ore.

This usually requires a scrubber up front to remove the clays and pump them to a tailings dam.

The DMS plant at Mt Tom Price suffered from these issues when first commissioned.

Source: METS Library
The standard manganese beneficiation plant includes a scrubber up front to remove clays.

This is because the downstream DMS plant cannot handle the clay in the feed.

• The main problem is to maintain bath density (sg) with ferrosilicon.

• Clays cause difficulties maintaining the sg difference.

Source: METS Library
For flotation where clays are present the consumption of reagents is higher and selectivity is adversely affected.

- At Mt Keith the flotation feed is deslimed using small polyurethane cyclones for exactly this reason.
- Improved flotation recovery is achieved as a result.
- Fine talc is naturally floatable-problem nickel flotation
- Copper project-clays soak up reagents-negative impact on selectivity/recovery
Thickening of clays is very difficult due to the fine particles (<2 microns) which are highly charged surfaces.

This requires flocculent screening and optimisation of the pH to achieve acceptable settling rates.

- The overflows can be dirty which may cause problems with downstream processing.
- In addition the presence of clays affects the ultimate underflow density and the choice of underflow pumps (positive displacement not centrifugal pumps).
Filtering of Clay Ores

> Pressure filters will always provide higher performance than vacuum filters.

> The nature of the clay and the volume percentage in the feed impacts adversely on filtration rates, clarity of filtrate, spillage and maintenance issues.

> Filter aids will increase filtration rates including, high pH, Coagulants, Guar and combinations of which all result in lower water recovery and have to be tested in the laboratory.

> The presence of clays causes excess spillage with clays sticking to cloths requiring washing and excess maintenance issues.

> Solution-guar, coagulants, diatomaceous earth

Source: METS Library
The tailings don’t beach and drying of a thin layer with a high insitu density is slow and difficult.

The economic and potential environmental issues are serious when treating high clay ores.

Water recovery is low
For high clay ores Tunra type testing to determine rill angles, angles of repose and materials handling characteristics is a must.

Only apron feeders are effective feeders with high clay ores. The use of stockpiles is not possible because of rat holing and the difficulties getting the ore to flow in a stockpile or bin is extreme.

Conveying is also difficult requiring the use of belt washing stations plus increased tracking issues.

Source: METS Library
Slurry Pumping

> Derates the capacity of slurry pumps

> Oversize pumps are another option to allow for the difficulties encountered when pumping highly viscous clay ores.

> Viscosity measurements are critical to plot yield stress against shear rate and benchmark this against other problematic ores.

> Pump selection is also an issue because highly viscous clay ores can derate the calculated pump capacity by up to 50%.

> For pumps under thickeners centrifugal pumps may be totally unsuitable and either peristaltic or mono pumps will be required.

Source: METS Library
Clays don’t settle and thickener overflow water or tailings return water is dirty as a result.

This dirty water causes problems in the water distribution system pipes, etc.
Conclusions Processing Clay Ores

> Understanding the geology, mineralogy and correctly selecting representative samples of the ore to be processed is critical in getting the mineral, processing right.

> Clays have the potential if not recognised to destroy project economics. Testing at an early stage of representative ore samples is critical.

> The presence of clays in hard rock comes as a surprise if not fully understood. Similarly waste dilution from country rock containing clay can adversely affect the process. There are some solutions which assist in processing ores but don’t negate all of the difficulties.

> The presence of clays has a major influence on the process selection and equipment used in the final flowsheet. The industry has paid a heavy price on a number of projects where the clay was not recognised or the process plant was based on a hard rock design which later proved to be totally unsuitable.

> Trying to mitigate the impact of clay on the process if the percentage of clay in the feed cannot be controlled is a mineral processing nightmare.
Acknowledgement

> Thanks to companies for permission to publish

> Thanks also to all colleagues, laboratory staff and other consultants for their help and contribution.

> Thanks to vendors for the photos
References


> Clay mineral nomenclature American Mineralogist.


> METS Library 2013

THANK YOU

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