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NIR Technology at Freeport McMoRan Mine Sites

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July 21, 2020

Outline

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- Overview of Freeport McMoRan's Mineralogy Department
  - Central Analytical Service Center (CASC)
  - Automated X-ray & NIR (AXN)
  - Technology Center Tucson (TCT)
- Technology Comparisons
- QA/QC
- NIR Data Use at Morenci and Safford mine sites

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Overview

North American Operations Served by CASC and AXN

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Bagdad
Safford
Miami
Morenci
Phoenix
Chino
CASC/AXN
Silver City
Tucson
Tyrone
Sierrita

AZ & NM Mine Site
City
CASC/AXN Lab

Overview of Freeport Technology Center Mineralogy Department

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AXN

- X-ray Diffraction Analysis (XRD)
- Near Infrared Analysis (NIR)
- Cation Exchange Capacity (CEC)

Process Mineralogy Lab

- Optical Microscopy
- Scanning Electron Microscopy
- Automated Mineralogy

Automated X-ray / NIR Overview (AXN)

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- Primary Instrumentation:
  - 7 X-ray diffraction (XRD) analyzers
  - 4 Near Infrared (NIR) analyzers
  - 3 Ion Chromatographs (CEC: Cation Exchange Capacity)
  - Automated pulverization circuit
- Provides bulk, clay and alteration mineralogy
- High throughput/fast turnaround/highly automated
- Linked to CASC robotic lines for daily blast-hole analyses
- Turn Around Time as fast as <24 hours
- Average workload of 3,000 XRD and 16,000 NIR analyses per month

AXN Robotic Circuit

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Technology Comparisons

Data Availability

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Factors

- Cost
- TAT
- Difficulty of Analysis

XRD/NIR - rapid, cost-effective non-destructive, accurate, & efficient analytical method making it ideal for linking with CASC robotic lines for daily blasthole analysis

QEMSCAN provides valuable information not obtained through XRD/NIR, but requires more complex sample preparation and analysis

Automated Mineral Analyzers

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- Labor intensive sample preparation, slower TAT
- Costly
- Detection limits under normal operating parameters
  - Unable to detect approx. <8 Wt.% elemental Cu in minerals
  - Requires SEM analysis to better define SIP definitions
  - Light element limitations (oxygen, carbon, hydrogen)
- Beam resolution on fine textures & phase intergrowths

XRD

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- Detection limits vary by mineral. Typically <=0.5%
  - Low grade copper minerals fall below detection limits
  - Not an ideal tool for Cu deportment
- Minor phases overlapped by major peaks - resolved by reconciliation with assay
- Preferred orientation of micas/molybdenite during press mounting
  - Press mounts are back filled
  - Topas software allows calculation for correction

XRD

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- Unable to detect amorphous non-crystalline material
  - Can be sample prep generated or natural
  - Use of CEC to estimate swelling capacity of sample (swelling clay)
  - Micronization - control amorphous & reduce microabsorption effects

NIR

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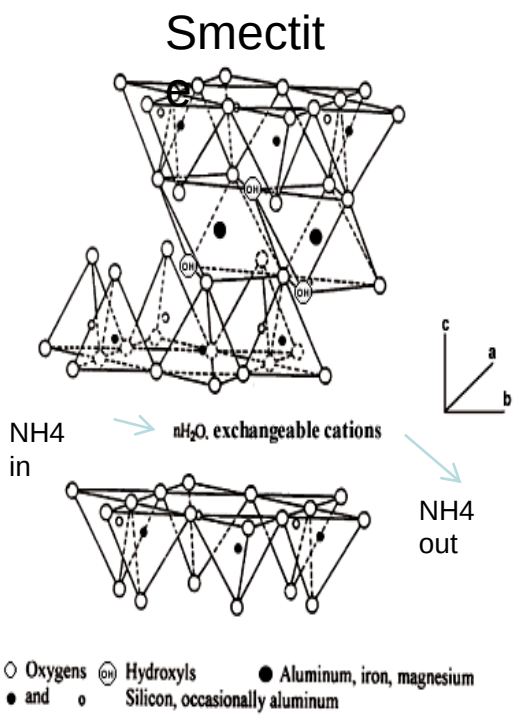
- Not applicable for Cu mineral deportment
- Limited by reference data – XRD & CEC
- Requires site specific calibration model & periodic model updates for quantitative predictions
- Limited spectrum, limited constituent set (clays, micas, chlorite)
- Reference data required for calibration models : XRD and CEC

Cation Exchange Capacity (CEC)



- Measures the quantity of cations (Mg, K, Ca, & Na) that a sample can exchange.
- Predicts swelling capacity and reported as swelling clay content.
- Most clays tough to quantify via XRD (amorphous).
- Normalized CEC value to XRD data for bulk mineralogy.
- Final measurements by ion chromatography.

Standard Mineral CEC Values

Kaolinite	3-15
Halloysite 2H2O	5-10
Halloysite 4H2O	40-50
Montmorillonite-group	70-100
Illite	10-40
Vermiculite	100-150
Chlorite	10-40
Glauconite	11-20+
Palygorskite-group	20-30
Allophane	~70

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QAQC

AXN - XRD

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- NIST Corundum standard analyzed daily on each XRD
  - EVA peak position and area plotted on control chart
- AXN Ore Standard (Granite) analyzed daily on each XRD
  - Synthetic standard being developed for XRD
  - Topas Rietveld refinement results for charting
- Minimum of 5% of samples are duplicated
- Blank (quartz sand) samples prepared daily to check for contamination
- Pulverizing mills checked weekly to ensure proper particle size is produced
- New development - Reconciliation of Rietveld analysis with chemical assay

AXN - NIR

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- Mylar Standard analyzed daily on NIR
- Site Specific Ore Standards analyzed daily on NIR
- M-distance >5 = Failed Model built into LIMS
  - Failed Model samples get CEC
- Random samples selected for XRD/CEC; Quarterly XRD/CEC vs. NIR correlation reports issued
- Model updates performed based on XRD-CEC/NIR correlations & excessive Failed Models

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Data Use

Morenci

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- NIR data used daily for shovel routing and ore blending & routing (critical)

- XRD data
  - Retroactive requests in areas that are identified “problematic”. Helps the mill to prepare ahead of time when they get back to these areas
  - Requests randomly selected to understand full bulk mineralogy in all areas

Safford

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- Daily blast hole submittals for NIR and select XRD
  - NIR – Basic gangue for rock type
  - CEC/NIR Clay – blending
  - XRD – Bulk and alteration mineralogy
- NIR, XRD, and CEC (clay) data used in geologic model
  - Model is provided to the engineers for ore routing, blending, and forecasting
  - Data is referenced at least once a day
- Minerals identified include: swelling clay, muscovite, biotite, kaolinite, chlorite
- NIR is quick & inexpensive ($6/sample), but requires spectral model to be built based upon XRD & CEC data
- Requires site specific calibration model & periodic model updates for quantitative predictions

Safford: NIR in Ore Control Modeling

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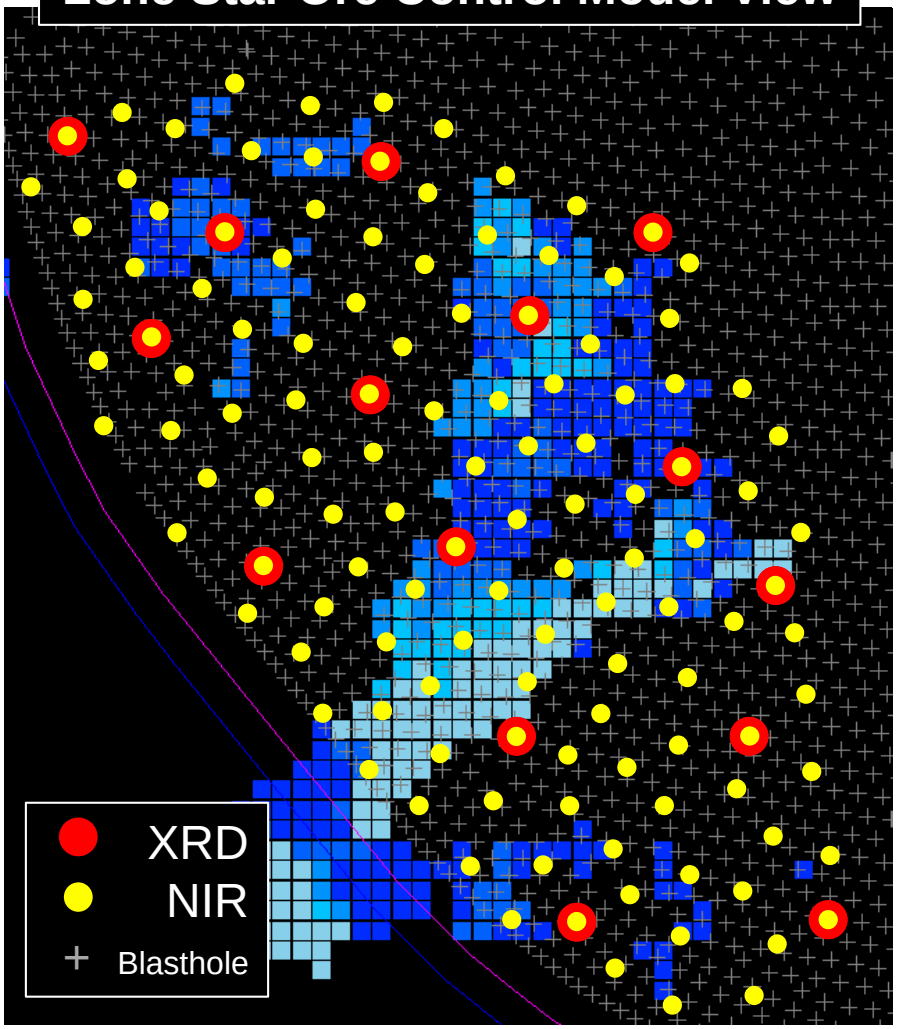
Ore Control Modeling

- **50%** of blastholes sampled for NIR, **20%** of blastholes sampled for XRD
- NIR data used to calculate **total clay**

  Total Clay = Kaolinite (%) + Swelling Clay (%)
- Total clay used to determine if **blending** is necessary

Lone Star Ore Control Model View



XRD is ~8x the cost of NIR per sample

Safford: Direct Application of NIR – Crush/Leach Circuit

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Effective Clay Blending:
• Prevents **clogging** of grizzly feeder in crusher • Allows for more **effective agglomeration** stage

Safford: Direct Application of NIR - Leachpad

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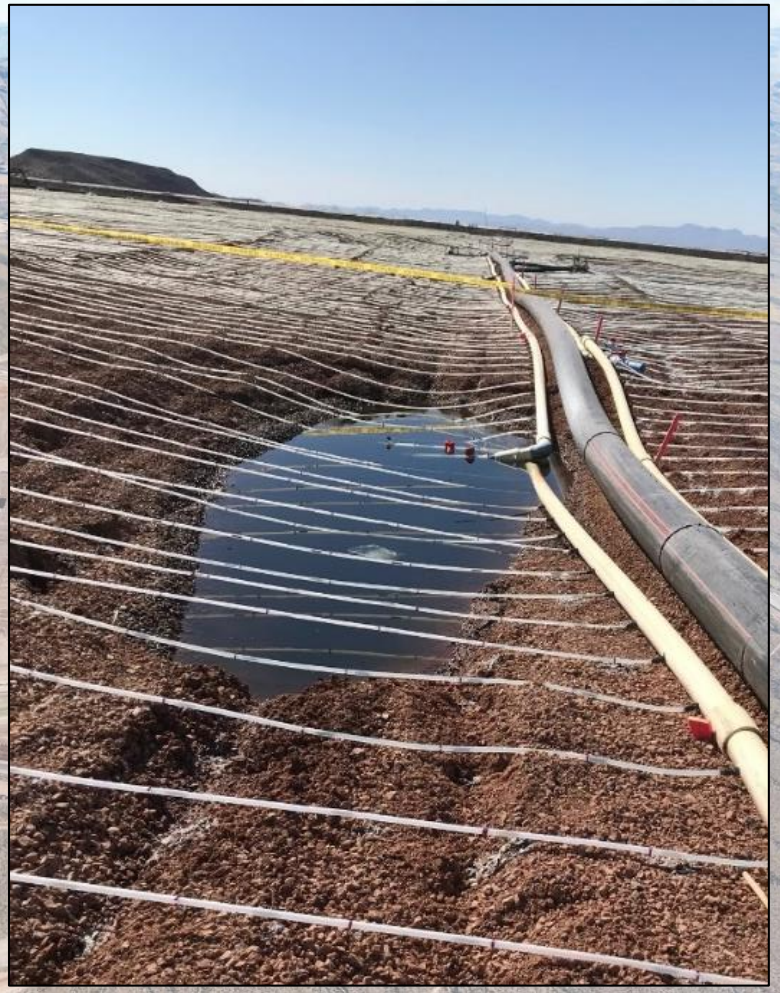
Effective Clay Blending:

- Allows for **effective percolation** of sulfuric acid down through lifts
- Prevents **geotechnical instabilities** in leach pad construction



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Questions?