
Mined Materials Geochemical Characterization Primer
Prepared for:
Hardrock Mining Geochemistry and Hydrology Workshop 1: Evaluating Water Chemistry Predictions at Hardrock Mine Sites
Sponsored by:
U.S. EPA Region 10, Office of Research and Development (ORD), and the Office of Superfund Remediation and Technology Innovation
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Boulder, CO/Washington, DC
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Linkages

Grasberg Open Pit, New York Times, 12/27/05

- Geochemical characterization – modeling – mine management
- Purpose of characterization and modeling is to guide management decisions
  - Which rock goes where in the field? Will water treatment be needed? Will mitigation work?
- Results of some geochemical tests used for field decisions, others as inputs to block or geochemical models

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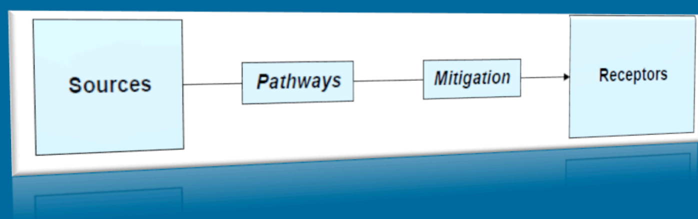
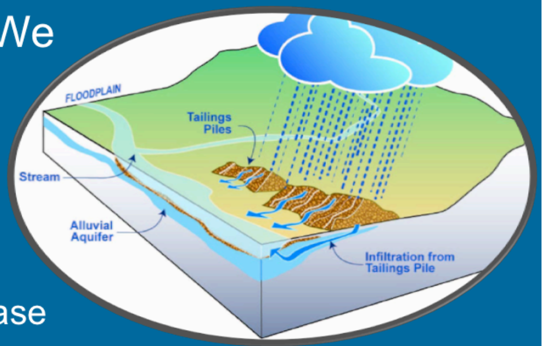
Geochemical Characterization of What?

- Mined materials (sources)
  - Tailings, waste rock, walls of open pits and underground workings, ore (why?), heap and dump leach materials, smelter slag, blended wastes, cemented backfill…



What Processes Are We Trying to Simulate?



- Earth processes
  - Dissolution, precipitation, acid/base
- Mining processes
  - Creation of tailings, waste rock, etc. – from crushed drill core
  - Blasting is rarely included – commonly missing contaminants of concern (NO_3/NO_2, NH_4)
  - Heap leaching (CN)

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The Real World: Waste Rock Yanacocha Mine, Peru

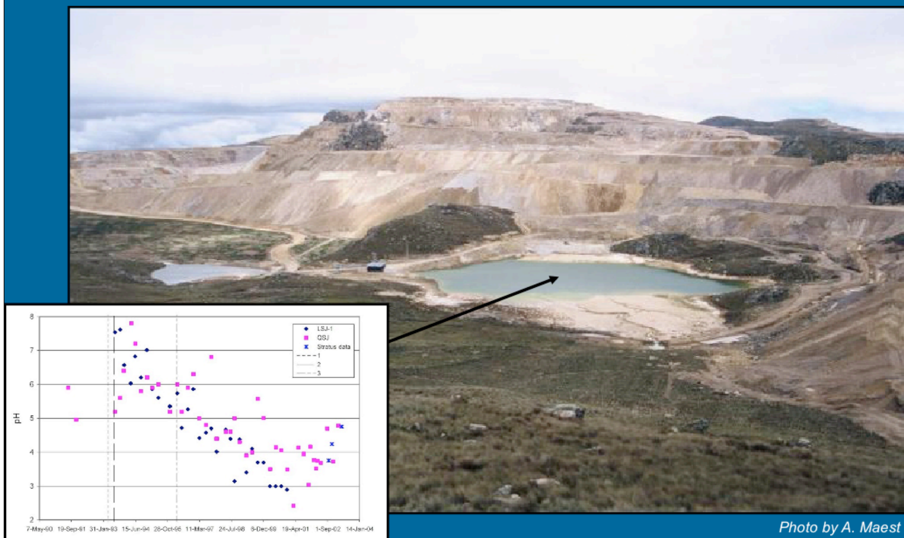

Photo by A. Maest

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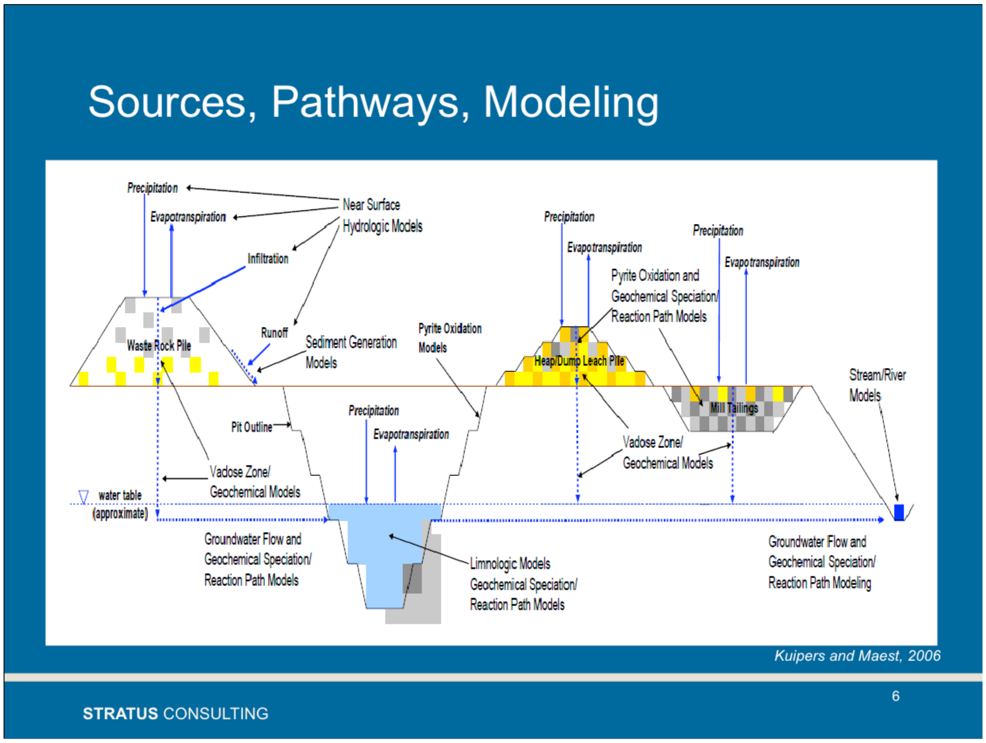
Sources, Pathways, Modeling
Precipitation
Evapotranspiration
Near Surface
Hydrologic Models
Infiltration
Runoff
Waste Rock Pile
Sediment Generation
Models
Pyrite Oxidation
Models
Precipitation
Evapotranspiration
Pyrite Oxidation and
Geochemical Speciation/
Reaction Path Models
Precipitation
Evapotranspiration
Heap/Dump Leach Pile
Mill Tailings
Stream/River
Models
Pit Outline
Precipitation
Evapotranspiration
Vadose Zone/
Geochemical Models
Vadose Zone/
Geochemical Models
water table
(approximate)
Groundwater Flow and
Geochemical Speciation/
Reaction Path Models
Limnologic Models
Geochemical Speciation/
Reaction Path Models
Groundwater Flow and
Geochemical Speciation/
Reaction Path Modeling
Kuipers and Maest, 2006
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Characterization Overview

Tintaya Cu Mine, Peru; photo by A. Maest

- Focus on new and expanding mines
- Basics: test units, # samples
- What methods are used to characterize the geochemistry of mined materials?
- What are the advantages, limitations, and uses of each method?
- What kind of characterization should be done in each phase of mining?

Geochemical Test Unit

Yellowstone: http://www.americansouthwest.net/wyoming/photographs700/purple-rock.jpg

- Most important phase of predictions is sample selection – capture variability
- Rock types of distinctive lithology, mineralogy, and/or alteration, mineral availability ("liberation")
- Should be as homogeneous as possible
- Could evolve during exploration/operation
- Examples: propylitically altered rhyolite, granodiorite with quartz-sericite-pyrite alteration
- Conduct full geochemical characterization on each unit

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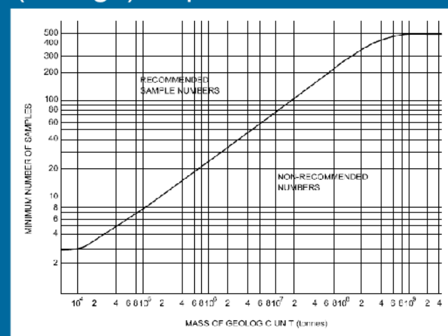
Sample Size

- *Suggested* samples/ton for each geochemical testing unit
- More homogeneous materials (tailings) require fewer samples
- Sample entire unit; put geochemical characterization information in block model

Mass of Each Separate Rock Type (tonnes)	Minimum Number of Samples
<10,000	3
<100,000	8
<1,000,000	26
10,000,000	80

Price and Errington, 1994.



US EPA, 2003 (BC AMD Task Force, 1989)

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How much is enough?

- No magic #
- Some statistical approaches
- Of course don't use this for # of HCTs, more geared toward ABAs and static testing

Geochemical Characterization Methods

- Static testing
  - Lithology and alteration zones
  - Whole rock analysis
  - Mineralogy
  - ABA, NAG tests
  - Short-term leach tests
- Kinetic testing
  - Humidity cell
  - Column tests
  - Field tests

Acid drainage at Eagle Mine, CO; photo by A. Maest

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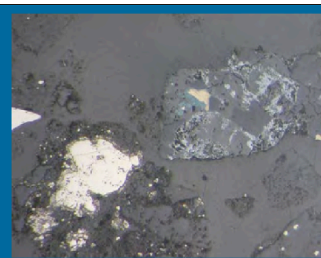
Lithology and Alteration Zones



Pebble deposit, Alaska; PLP, 2011, App. 11E; pyrite, chalcopyrite

- *What*: Rock types and alteration overprints
- *How*: Borehole logs, petrographic/mineralogic analysis, block model
- *Use*: ID geochemical test units
- *Limitations*: Sample representativeness

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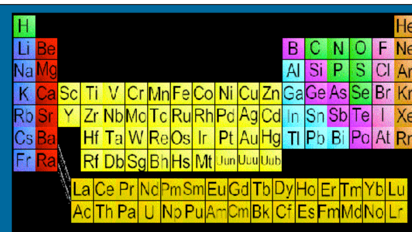
Whole Rock Analysis

Pinson Mine, NV, heap leach monitoring; photo by A. Maest

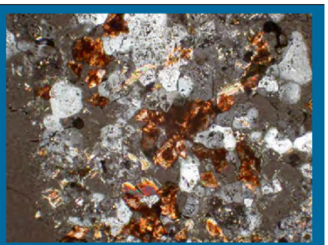
- *What*: Total concentrations of metals, etc., in rock/waste
- *How*: Grind sample, acid digestion, analyze for metal, etc., content by XRF, ICP, -AES, -MS…
- *Use*: ID overall contaminant levels in rock types
- *Limitations*: Detection limits, interferences; does not provide information on mineralogy

Constituents of Interest/ Concern



- Start bigger, get smaller
- Solids, liquids (charge balance if liquids)
- Focus on potentially toxic constituents, AGP/ANP
- General: pH, SC, alkalinity, acidity, TDS
- Metals
  - Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mo, Mn, Na, Ni, Pb, Sb, Se, Tl, V, Zn…
- Non-metals
  - Cl, CN, F, NH_4, NO_3/NO_3, S, Si, SO_4 …

Mineralogy



Pebble deposit, Alaska; PLP, 2011, App. 11E; carbonate replaced by hematite

- *What*: ID minerals and poorly crystalline substances present in rock/waste samples
- *How*: Optical microscopy, XRD, electron microscopy (SEM, TEM, HR-TEM), sulfide oxidation index/Rietveld analysis, AVIRIS (remote spectral imaging)
- *Use*: ID controls on solubility, identity source of AGP/ ANP, mineral availability ("liberation")
- *Limitations*: Need specific expertise to interpret results, not great for secondary minerals, representativeness

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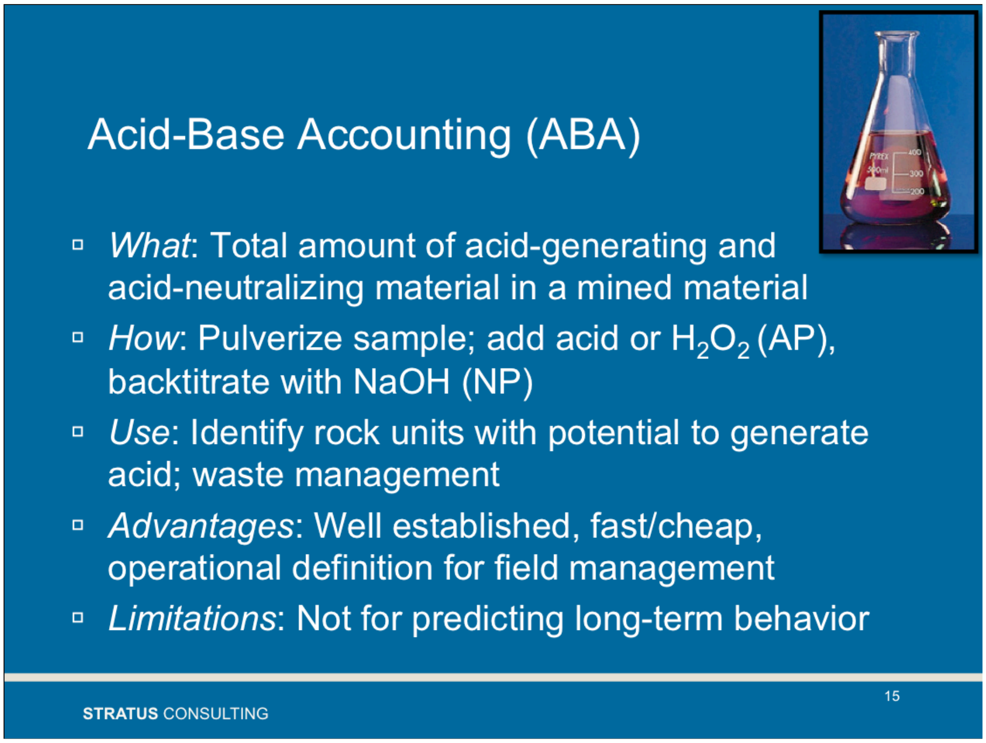

Kinds of sulfur: total, pyritic, sulfide, organic, sulfate

Part of acid-base accounting (ABA) testing; distinguishes between forms with more (pyritic, sulfide) and less (organic, sulfate) acid generation potential (AGP)

Issues: which form to use in AP (over/under-estimate AGP), does not confirm identity of minerals that contain the sulfur

Primary Sources of AP and NP

Melanterite
http://www.mindat.org/min-2633.html

- Acidity
  - Pyrite, pyrrhotite, marcasite, chalcopyrite, arsenopyrite…
  - Certain Fe sulfate minerals
  - Siderite
- Neutralization potential
  - Calcite, dolomite
  - Certain aluminosilicates (more likely at lower pH values)

Pyrite in limestone
http://www.mindat.org/min-3314.html

Good summary: Plumlee, 1999.

~ ABA Testing Methods

Equity Silver Mine, Canada; photo by A. Maest

- *Modified Sobek (pH 7),* Lapakko (pH 8.3), BCRI, BCRC, siderite correction
  - Most commonly used
- NCV (Newmont): no titration, infrared for C and S
  - Only includes carbonate minerals in NP
  - Can overestimate NP if siderite present
- NAG (Net Acid Generation): H_2O_2 + NaOH
  - Commonly used in Australia, screening only, fast
  - Does not distinguish between AP and NP

ABA/Static Testing: Main Sources of Uncertainty

Cananea Cu Mine, Mexico; photo by A. Maest

- Crushed sample – assumes all AP and NP available
  - Fracture surface vs. groundmass, encapsulation
- Final pH < 6: overestimate NP (silicates)
  - Modified Sobek and Lapakko pH 6 most reliable and conservative (Sobek > modified Sobek > BC Research > Lapakko)
- Mineralogy unknown – compare to "mineralogic" AP and NP
  - Especially important for low S, low NP wastes

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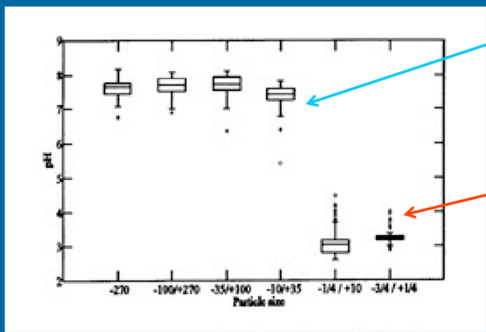
Grain Size and Mineral Availability



Lapakko et al., 1998; http://wvmdtaskforce.com/proceedings/98/98LAP/98LAP.HTM

Smaller waste rock particles made neutral/ slightly basic drainage

Larger waste rock particles created acidic drainage

Interpretation of ABA Results

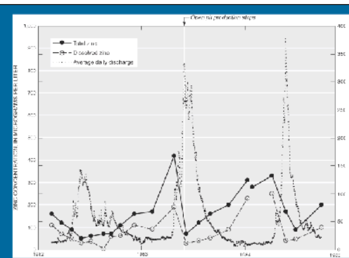
Acid drainage at Eagle Mine, CO; photo by A. Maest

- Many options that rely on %S and/or NP, AP
- NP:AP, NNP (NP-AP), NCV ranges, etc.
- Ideally compare to kinetic testing results or actual mine drainage
- NP:AP
  - Likely not acid-generating: > 3 (or 2 or 4)
  - Uncertain: 1–3 (or 2 or 4)
  - Potentially acid-generating (PAG): < 1 (or 0)

Short-term Leach Testing

- *What*: Readily soluble components of mined materials; some states have regulatory levels (often 100x MCLs)
- *How*:
  - Synthetic precipitation leaching procedure (SPLP) (20:1 = water:rock ratio)
  - Nevada meteoric water mobility procedure (MWMP) (1:1)
  - California waste extraction test (WET) (10:1)
  - British Columbia special waste extraction procedure and modification (BC SWEP) (3:1)

Short-term Leach Testing (cont.)



Questa Mine, NM, graph: Maest et al., 2004; http://pubs.usgs.gov/sir/2004/5063/

- *Advantages/use*: Estimates leached concentration ranges from storm/hydrologic events
- *Limitations*:
  - – Avoid use of unweathered materials
  - – Not for predicting long-term behavior – only 18–48 hr tests
  - – Water:rock ratio (Nevada MWMP has lowest w:r ratio, more conservative for arid climates)

Kinetic Testing

- *What*: Estimates long-term potential to generate acid and other contaminants
- *How*: Crush rock, apply water, measure
  - Laboratory kinetic tests
    - Humidity cell
    - Column (aerated, subaqueous)
  - Field kinetic test
    - Waste rock or tailings test piles
    - Wall washing
    - Minewall approach (Morin and Hutt, 2004)

2-yr kinetic tests, Montana Tunnels, MT; Photo by A. Maest

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Crush rock (<6.3 mm for waste rock, 150 mm for tails), place in column

HCT: 3-d alternating humid air/dry air cycles, flush every week, 20+ wks

Measure pH, sulfate, metals, etc. in leachate

Column tests – larger columns and particle size (<~25 mm), “trickle leach”

Kinetic Testing (cont.)

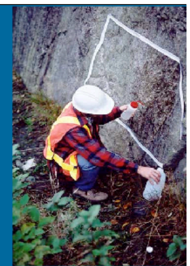

Photo: http://www.gardguide.com/index.php/Image:WallWashing.jpg

- *Advantages/uses*: Acid production rates, long-term weathering, input to geochemical models
- *Limitations*
  - Representativeness, focus on uncertain ABAs
  - Field/lab discrepancies: particle size
  - Length of tests: 20 weeks standard HCT length; too short for most materials, especially if higher NP
    - Lapakko: tailings with 1.3 wt% calcite and 6.6 wt% pyrite took 112 weeks to generate acid; mix of rotary kiln fines and rock with 2.1 wt% S from Duluth complex took 581 weeks to produce acid

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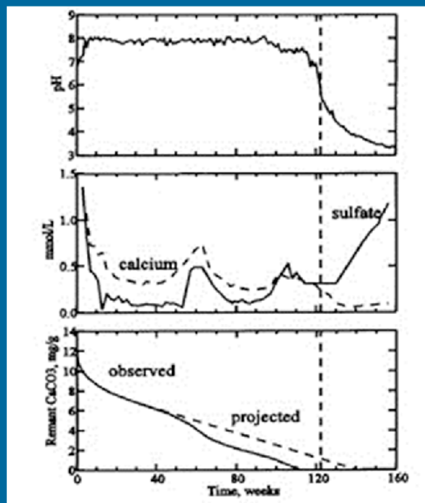
Should run kinetic tests on samples with full range of ABA results – need to know concentrations for input to geochemical models

Kinetic Tests: Examples



Lapakko et al., 1998; http://wvmdtaskforce.com/proceedings/98/98LAP/98LAP.HTM

- pH < 6 at week 122
- [Ca] < [SO_4] shows NP rate < AP rate
- All calcite depleted at week 112
- NP:AP = 0.09

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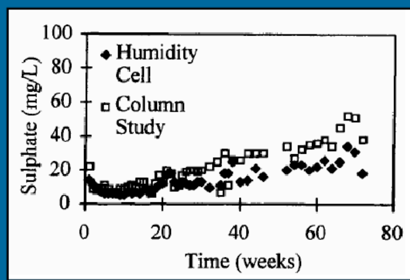
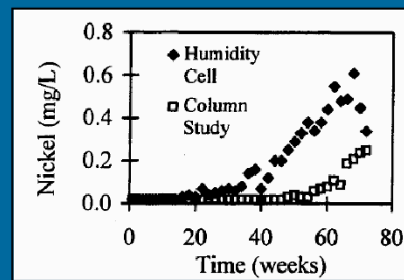
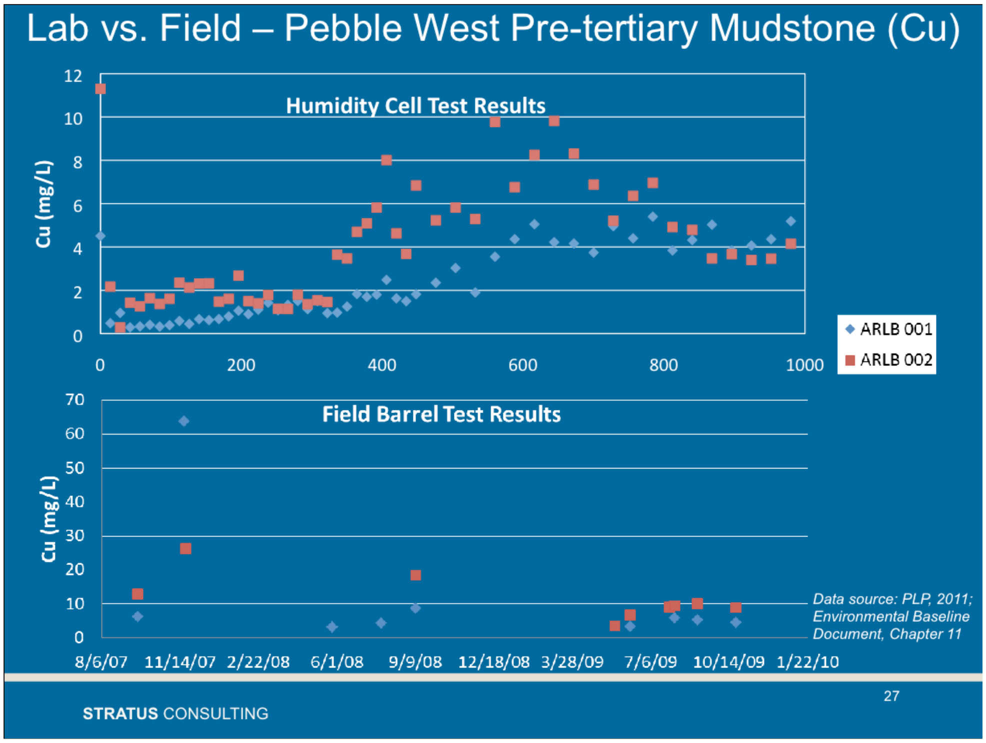
Kinetic Tests: Examples (cont.)





Nicholson and Rinker, 2000

- Metal leaching under neutral pH conditions
- Comparison of HCT and column test Ni and SO_4 concentrations

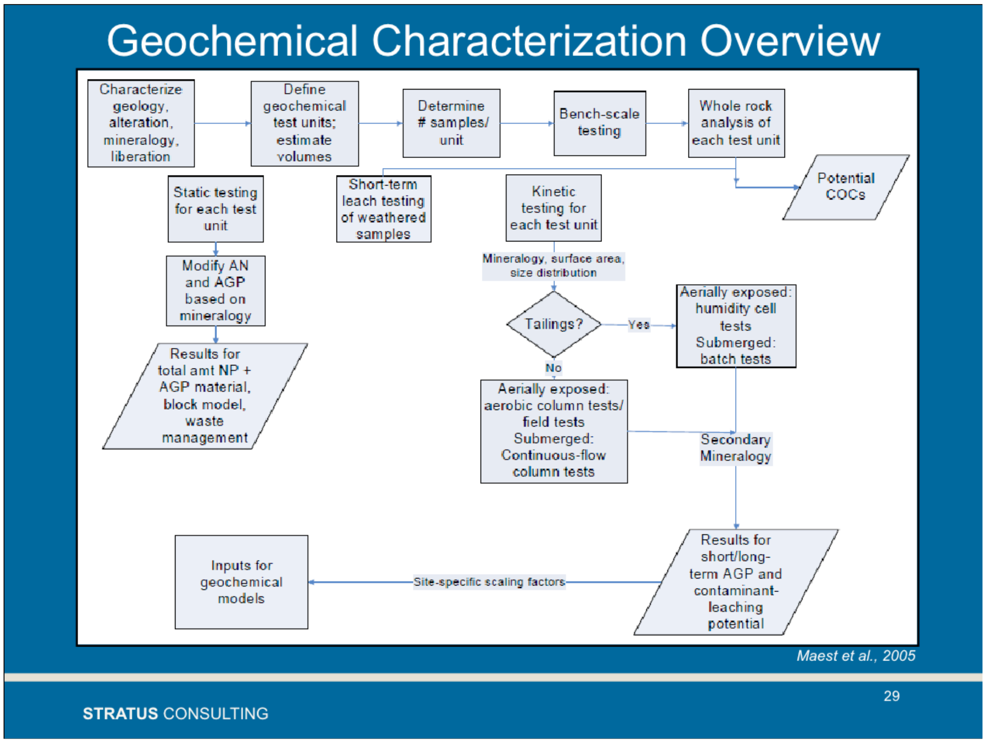


- Compare field and HCT splits
- First flush in weathered, then decreasing concentrations – "steady state" = last 5 week average
- Different trends if weathered or not
- Need to run even if ABA is PAG – to know concs for inputs to models

When to Characterize?

See Maest et al., 2005 for more detail; Tintaya Mine, Peru, ball mill; photo by A. Maest

- Exploration
  - Static testing (lithology, mineralogy, ABA…)
  - Geochemical testing units, block model
- Mine development
  - Continue static, start kinetic including field tests
- Operation
  - Continue lab/field testing; predicted/actual comparisons; waste leachate samples
- Closure
  - Continue lab/field comparisons


Geochemical Characterization Overview
Characterize geology, alteration, mineralogy, liberation
Define geochemical test units; estimate volumes
Determine # samples/ unit
Bench-scale testing
Whole rock analysis of each test unit
Potential COCs
Static testing for each test unit
Short-term leach testing of weathered samples
Kinetic testing for each test unit
Modify AN and AGP based on mineralogy
Results for total amt NP + AGP material, block model, waste management
Mineralogy, surface area, size distribution
Tailings?
Yes
No
Aerially exposed: humidity cell tests Submerged: batch tests
Aerially exposed: aerobic column tests/ field tests Submerged: Continuous-flow column tests
Secondary Mineralogy
Results for short/long-term AGP and contaminant-leaching potential
Site-specific scaling factors
Inputs for geochemical models
Maest et al., 2005
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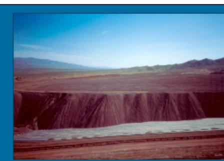
Summary



Rayrock Mine, NV, heap leach pad; photo by A. Maest

- Geochemical characterization aims to identify potential contaminants of concern and simulate range of concentrations under mining conditions
- Purpose is to inform mine management, including waste/ore placement, water quality monitoring, need for and type of water treatment and mitigation, effectiveness of mitigation measures
- Very few required tests or interpretation approaches
- Each method has advantages and limitations, and real crux is interpretation of results
- Need to compare predictions from tests to real conditions as mining proceeds

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