

Comparing Geochemical Test Methods on Porphyry Copper Tailings in Arizona

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Work performed for
BHP Copper Inc. San Manuel Operations

Introduction

- u Porphyry copper deposits contain chalcopyrite, pyrite, and other sulfides



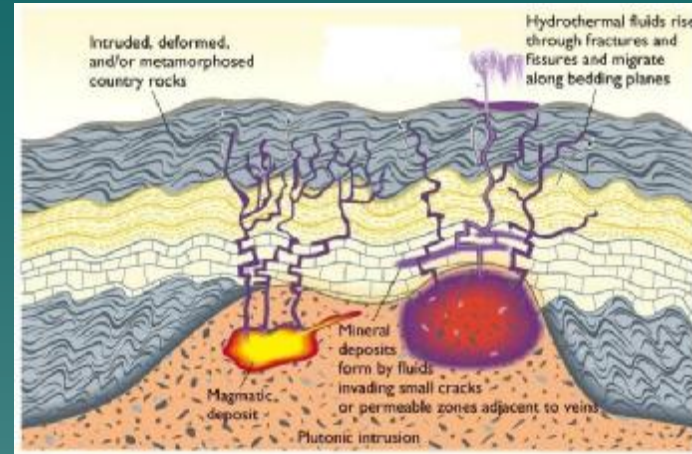
chalcopyrite



pyrite



molybdenite



Disseminated ore in quartz monzonite porphyry

Tailings = residue of beneficiation

- u Ore ($<.7\%$ Cu) is crushed and ground with water and concentrated
- u Rock/water slurry is put through flotation with frothing and collector agents
- u Material on bottom is partially dewatered and discharged to tailings ponds
- u Mostly inert material - ($>99\%$) quartz, feldspar, clays, carbonates
- u Very fine grained (clay, silt and fine sand sizes)

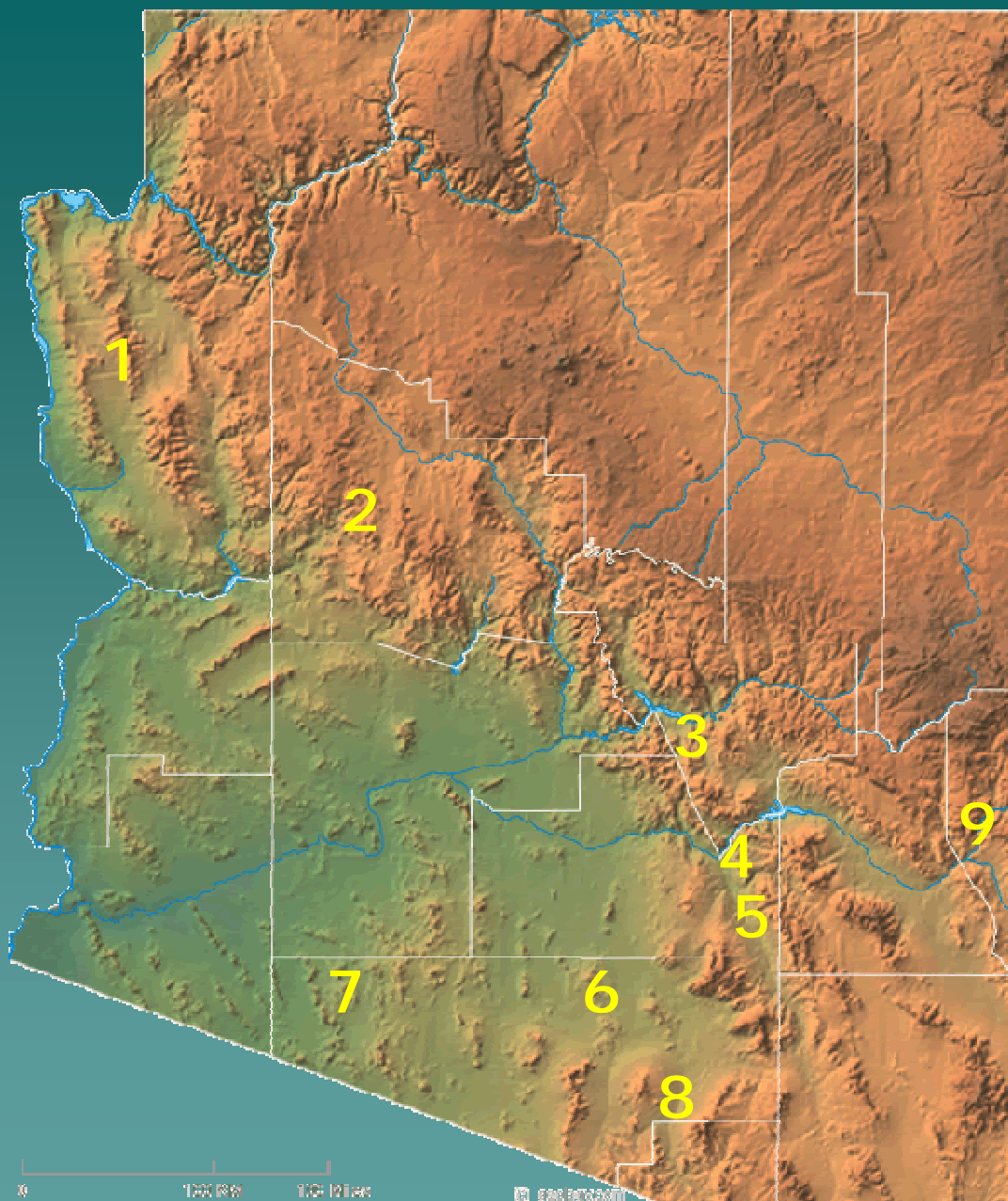


Purpose

- u BHP Copper Inc. contracted SRK to perform tailings characterization for engineering design, numerical groundwater modeling, and other demonstrations for Aquifer Protection Permit application for area-wide closure
- u Are the results from San Manuel tailings similar to those from other porphyry copper tailings in Arizona?
- u Examined limited number of public files at Arizona Dept. of Environmental Quality to gather geochemical data
- u Compared the public data to the San Manuel results

Arizona porphyry copper mines in study

- 1 Mineral Park
- 2 Bagdad
- 3 Miami
- 4 Ray
- 5 San Manuel
- 6 Silver Bell
- 7 Ajo
- 8 Sierrita
- 9 Morenci



San Manuel Observations and Hypotheses

- u Acid-Base Accounting over-estimates acid generation potential
- u Humidity cell tests show only fraction of sulfide will be oxidized long-term

What accounts for the difference?

- u Acid may be neutralized by alkaline process waters and secondary carbonates in tailings
- u Mineralogy of tailings may block oxidation

Analyses Used to Compare Tailings

- u Acid-Base Accounting
- u Synthetic Precipitation Leaching Procedure
- u Humidity Cell Testing
- u Mineralogy

Acid-Base Accounting

- u Potential for material to produce net acid conditions if all sulfides oxidize
- u Modified Sobek method accepted by ADEQ and EPA
- u Acid generation potential (AP) obtained from LECO analysis of sulfur speciation
- u AP = amount of CaCO_3 required to neutralize the produced sulfuric acid, assuming all sulfur is converted to sulfuric acid
- u NP = Neutralizing Potential = obtained by titration of the reaction product with acid to a set pH (4.3 to 8.3 for the back titration), then analyzing for total inorganic carbon and calculating the carbonate content, assuming all inorganic carbon is present as CaCO_3 .

ABA terms

- u Acid generating = Net Neutralizing Potential (NNP) < -20 equiv. kg CaCO_3 /metric tons material or $(\text{NP}/\text{AP}) < 1$
- u Neutralizing = $\text{NNP} > +20$ equiv. kg CaCO_3 /metric tons material or $\text{NP}/\text{AP} > 3$
(CA, NV, AZ; others different)
- u Uncertain = in between

$\text{NNP} = \text{NP} - \text{AP}$ (Neutralizing Potential minus Acid-generating Potential)

SPLP

- u Synthetic Precipitation Leaching Procedure
 - Static test
 - Leachable element assessment
 - pH 5 water in 20:1 liquid to solid ratio, agitate slurry for 18 hrs, analyze leachate

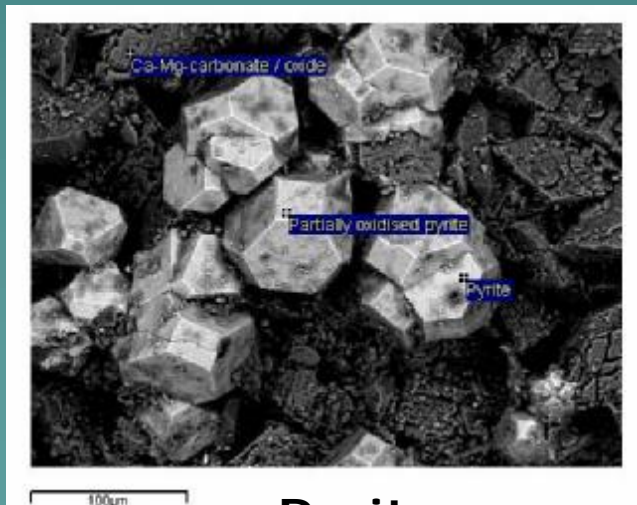
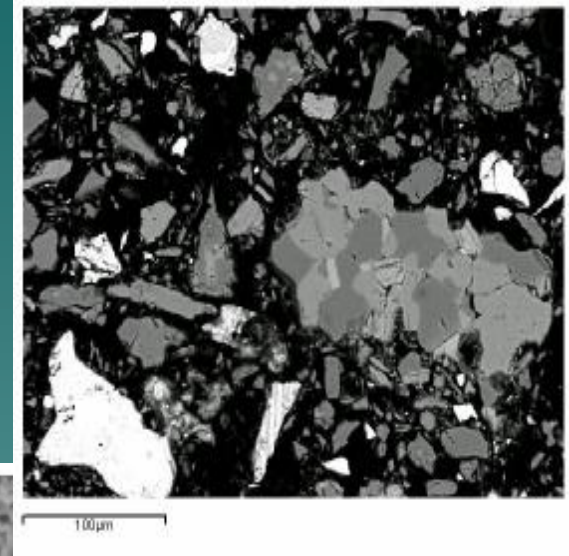
Humidity Cell Testing (HCT)

- u 40 week program (equivalent to thousands of years of meteoric water infiltration)
- u Slow weathering after initial flush (6 cycles) - even embankment cyclone sand
- u Cyclic pH variation but low EC after initial flush, post-released salts
- u Minimal sulfide oxidation

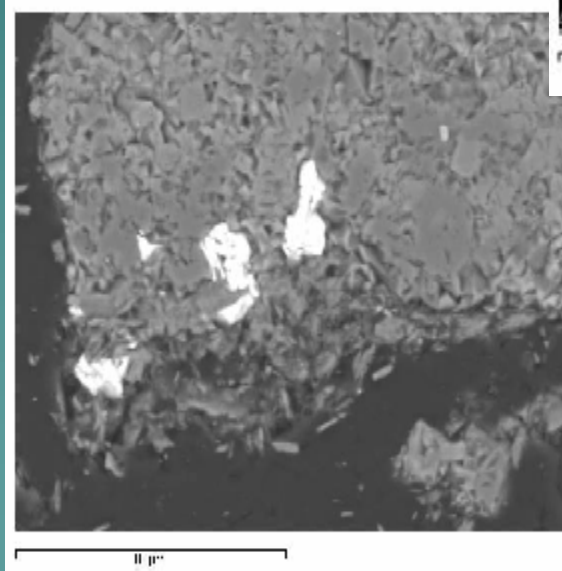


Tailings Mineralogy

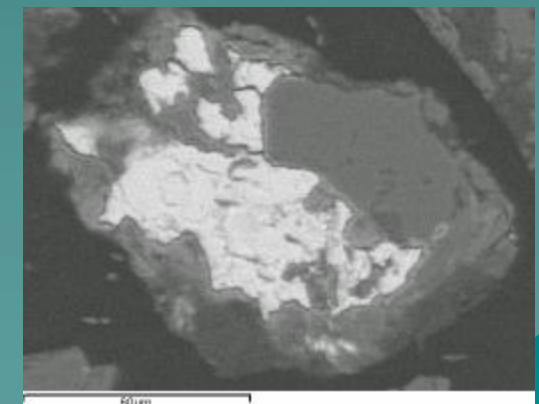
- Quartz, illite, kaolinite, feldspars, muscovite – 99%
- Sulfides - <1% - mainly encapsulated in silicates, crystalline, and small grain size (<80 μm)



Pyrite



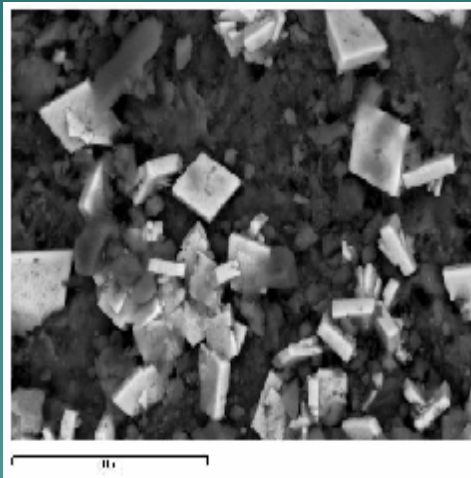
Chalcopyrite in illite



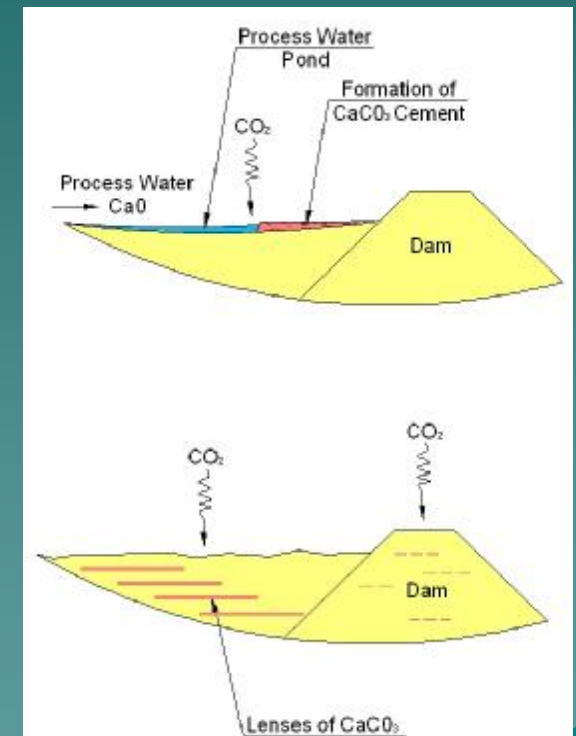
Pyrite in quartz

Tailings Mineralogy - carbonates

- Carbonates in lenses as matrix support to detrital silicates - mainly calcite, siderite & ankerite



- Secondary minerals-mainly on embankment walls; Fe-Cu-Al sulfate and hydroxy-oxides
- Not all carbonates produce alkalinity



San Manuel Test Results

Method	Results
Contact test	Acidic and reactive tailings on embankment walls; Alkaline at depth & in beach (flats)
Total metals	Some enriched metals in tailings. Tailings not a significant environmental/health risk
Acid Base Accounting (ABA)	Potential for all tailings to become acid
Synthetic Precipitation Leach Procedure (SPLP) (EPA 1312)	Low reactivity of material
Porewater analysis	Concentrations similar to SPLP. Solubility controls chemistry
Mineralogy	Only part of sulfide is available to react; reaction barrier. Reactive carbonates present in tailings
Humidity Cells	Low level of reactivity
Accelerated leach tests	

San Manuel

Surface

- u pH = 6.5-8
- u EC = 3,000
- u NNP = -98 to 213
- u NP/AP = 0.06 to 214
- u ABA = acid to neutral
- u HCT = neutral to alkaline after 3 weeks (40 weeks testing)



Fresh tailings & at depth

- u pH = 9
- u EC = 500
- u NNP = -1.7
- u NP/AP = 6.83
- u ABA = uncertain to neutral
- u HCT = no AWQS exceedances after 25 weeks

Bagdad

Mulholland

- u pH = 9.7
- u EC = 1,800
- u NNP = 15 to 30
- u ABA = uncertain
- u HCT = weakly AP after 7 weeks (20 weeks of testing)

Mammoth Wash

- u HCT = not AP after 7 weeks



Sierrita

- u NNP = -30 to 2
- u NP/AP = 0.04 to 1.09
- u ABA = acid
- u HCT = not AP in short term (10 weeks testing)



Miami

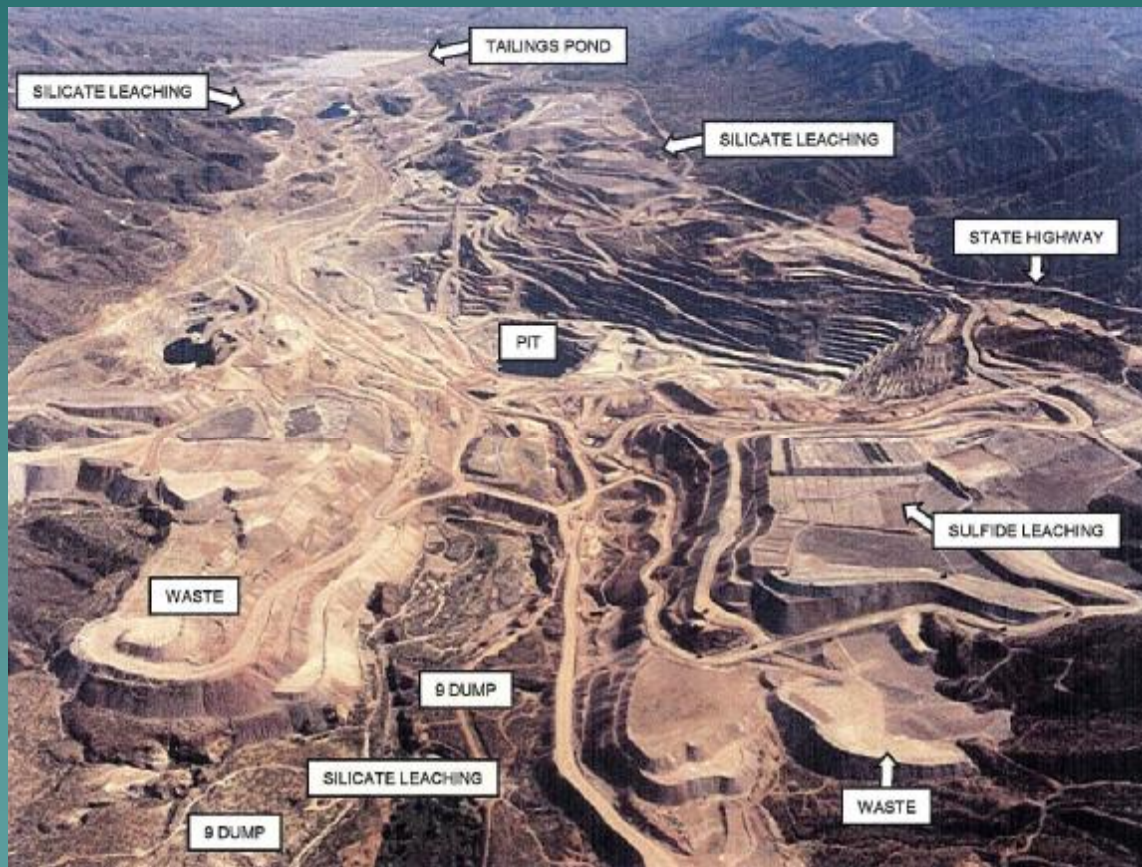
- u pH T5 = 7.9 ave
- u NNP = -12 to +19
- u ABA = Acid to uncertain
- u pH T6 above 40' = 4.8
- u pH T6 below 40' = 8.1



Ray

AB-BC Tailings

- u pH = 7.0
- u NNP = -38 to -5
- u ABA = acid
- u HCT = pH 4.4 to 5.3 (10 weeks of testing)



Silver Bell

Tailings 1 and 2

- u pH = 6.7 – 8.4
- u NNP = -51 to 95
- u NP/AP = 0.04 to 3.21
- u ABA = acid to neutral



Mineral Park

Surface

- u pH = 3.8
- u EC = 7,650
- u NNP = -54 to -44
- u ABA = acid

At depth

- u pH = 5.7 - 7
- u EC = 2,500
- u NNP = -44 to 166
- u NP/AP = 0.1 to 177
- u ABA = acid to neutral



Ajo (New Cornelia mine)

- u pH = 8 – 8.6
- u NNP = -13 to 207
- u ABA = uncertain to neutral



San Manuel Observations and Conclusions

- u Acid-Base Accounting over-estimates acid generation potential
- u Humidity cell tests indicate only a fraction of sulfide will be oxidized long term

What accounts for the difference?

- u Acid is neutralized by alkaline process waters and secondary carbonates in tailings
- u Sulfides are encapsulated in silicates and protected from oxidation

Conclusions at San Manuel

- u Acid Generation
 - Low potential
 - Greater on embankments than beaches
 - Mineral control: sulfides encapsulated (30 to >90%)
 - Carbonate widespread
 - Alkaline process water
- u AWQS element release
 - Low leaching
 - Encapsulated sulfide minerals
 - Humidity Cell Tests - Sb, Cd, Ni, F from sands in early weeks
 - No AWQS exceedances predicted at POC for > 500 yrs



Conclusions for Mines in Study

- u Acid-Base Accounting over-estimates acid generation potential
- u Humidity Cell Tests show not acid-generating
- u Acid may be neutralized by alkaline process waters and secondary carbonates in tailings
- u Depending on sulfide mineralogy, sulfides may be encapsulated in silicates



SM before reclamation



SM after rock armoring, cover

General Conclusions

- u ABA should be used as a screening-level assessment only
- u ABA assumes all sulfide goes to acid
- u Need Humidity Cell Tests for accurate assessment of long term oxidation potential
- u At San Manuel, most sulfides are encapsulated or are neutralized by alkaline process water

Significance for Environmental Managers

- u ABA tests, though cheaper, could significantly increase long term costs, if decisions made based on high AP
- u Humidity Cell Tests provide accurate data to make engineering designs for tailings closure
- u HCT, though more expensive, may save money long term, if tests indicate tailings are not as acid-generating as ABA tests indicate

San Manuel tailings after closure



QUESTIONS?