Mining Ores of Northern Chile

By:
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Michal Sullivan
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Geology of Northern Chile

- The Chilean Iron Belt
  - mineralization episode during the Andean orogeny.
  - 40 mineral deposits
- Andean orogeny
  - Convergent boundary
  - Paleozoic and Precambrian periods.
- Most of the mineral deposits were created from magmatic hydrothermal activity.
  - The water required to form those deposits derived from the subducted slab of the oceanic crust beneath the Andes.

(Moreno and Gibbons, 2007)

Location: Candelaria Mine

- Located near in the Atacama Region of Copiapó Province, near Copiapó, Chile
- Open pit mining since it opened in 1983
- Composed of Permian to Lower Cretaceous rocks.
- The Candelaria mine is part of the Punta del Cobre formation in the Chañarcillo Group
- Candelaria mine consists of chalcopyrite, magnetite, pyrite, pyrrhotite, and sphalerite.

Fun Fact:

Within the next year, suspected yield is 184 kilotons of copper, 105,000 ounces of gold, and 1.8 million ounces of silver

https://www.sec.gov/Archives/edgar/data/831259/000083125914000006/a2013form10-k.htm

Diagram Credit: SRK Consulting
What are Supergenes?

Supergene: A natural concentration process that gives an unusual abundance of a desired element (typically copper or gold).

Why are They Important?

They cause a natural mineral deposit to have greater mineral concentration and higher economic value.

The Very Basic Concept?

Leaching of valuable elements from the upper parts of mineral deposits to greater depths where they precipitate and produce higher element concentrations.

(Harraz. H, 2013)
Supergenes - the Basics

- Supergene enrichment is essential for the economic viability of many porphyry copper deposits.
- Surface oxidation produces acidic solutions that leach minerals.
- Solution percolates downward until it reaches past the water table.
- Once the water table is reached reducing conditions become more favorable.

(Harraz H, 2013)

Oxidized Zone -> Leaching
Supergene Zone -> Enriched
Protore -> Unaltered Parent Material

Diagram Credit: Harraz H. 2013
Morphology of Zoning

Most common minerals in **Oxidized Zones**:
- Copper: malachite, azurite, Chrysocolla, cuprite
- Gangue Minerals: Quartz, barite, calcite
- Iron: Goethite, hematite, pyrite
- Lead: anglesite, cerussite
- Manganese: pyrolusite
- Nickel
- Silver
- Zinc: Smithsonite

Most common minerals in **Supergene Zones**:
- Copper: Chalcocite, bornite, covellite
- Lead: Galena
- Nickel
- Silver
- Zinc: sphalerite, wurtzite
Background: Talcuna Mine

- Northern Chile
- Cu and Mg deposits (Munoz, 1975)
- Stratiform Cu deposits (Talcuna Mine)
  - Confined within strata
  - Hydrothermal deposits (Morales, 2005)
  - *Quebrada Marquesa Formation* (Morales, 2005)
  - Low grade metamorphism
- Alteration: chlorite-epidote-calcite-albite, prehnite, zeolite (Oyarzun, 1998)
- 2 Events
  - Early manganese deposit (Oyarzun, 1998)
  - Late vein deposit (Oyarzun, 1998)

Background: Montecristo

- Mancilla Plutonic complex
- Iron oxide vein
  - Copper and Iron
- 10 m thick, 1000 m long
- Localized with diabase dykes

(Espinoza Et Al., 1996)
location: Montecristo Mine
Guiding Questions

- Minerology
  - Host rock
  - Ore mineral
- Protolith
  - Copper source
- Geologic story
  - Cause of metamorphism
  - Potential metamorphic facies
Methods: Thin Section

- Cut hand sample to the appropriate length and width to neatly fit on thin section
- "Glue" or use epoxy as a 10:3 ratio and stick the cut rock sample to prepared slide
- Grind sample starting with 400 grit on a glass plate and continue to increasing finer grades (600 grit and 1000 grit)
- Polish sample using 1 micrometer diamond grit and if necessary move down to 0.25 micrometer or even .05 micrometer grit size.

Epoxy
- Similar 10:3 ratio with sample placed in a container for a specific mold size.
- Epoxy sample under went same polishing procedures.
Methods: S.E.M.

- Preparation
  - Put a Strip of copper on sample (polished section)
  - Coat with Carbon
- JEOL JSM-6490LV SEM_EDS
  - Elemental analysis
- Analysis
  - Test data against theoretical
Methods: Point X-Ray Diffraction

- Preparation
  - Polished section
  - Isolated crystals on slide
- Bruker AXS D8 Discover
  - Point analysis
  - Vertical mount
  - Spin for pattern
- Analysis
  - X’pert
  - Manipulate/match pattern
  - Compare plausible patterns
### Data: Las Pintadas

Possible Cl contamination?
Data: Las Pintadas
Data: Las Pintadas
Data: Las Pintadas Mine

XRD

- Less distinctive XRD pattern due to the nature of the sample
- Sample was rotated throughout the process
- Sample was purposefully oscillated to generate more randomized data
- The oscillation may be extended beyond the crystal surface and started scanning the epoxy instead, which could be the reason for the abnormal trend

Values Generated for Chrysocolla
Values generated for Atacamite

Much better data match than the previous sample
- This sample only underwent rotation instead of rotation and oscillation

Strong peak match for Atacamite, but there is still strong variation because this was a crystal sample and not a powdered sample

The XRD standard for Atacamite was actually taken from the same province as my sample in Chile!
Thin Section (FoV 5mm)

Minerals found in thin section:
- Goethite
- Actinolite
- Iron Oxide
- K-spar
- Quartz
- Atacamite
- Calcite
- Magnetite
Data: Montecristo S.E.M

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Data Talcuna: Thin Section

Common
• Chlorite
• Albite (vein)
• Barite

Less Common
• Olivine
• Epidote
• Calcite
Data Talcuna: X Ray Diffraction

Host Rock: Point XRD
• Experimental
• Barite XRD pattern

Ore: Point XRD
• Inconclusive
Data: Talcuna Mine S.E.M.

Results: SEM Location

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<th>Location 1</th>
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Data: Talcuna Mine

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Discussion: Candelaria Mine

- The SEM data, XRD, and Thin Section all have strong levels of atacamite present.
- Strange because atacamite can only form in highly saline fluids, whereas supergene enrichment is formed as a result of slightly acidic rainfall water. (Eion et al. 2006)
Proposed Theory

- The original supergene formed and deposited material 44 to 9 Ma.
  - During a period of arid environment where there was just enough rainwater to supply the process. (Eion et al. 2006)
- The atacamite actually formed much more recently (< 2 Ma).
- Current Hypothesis: the saline, Chlorine rich water necessary for formation is the result of sedimentary rocks.
  - Brought up from tectonics
  - Dissolved salts from these rocks mixing with the evaporating meteoric water to create hyper-saline water. (Eion et al. 2006)
- This only occurs along fault zones filled with porphyry rock.

Photo Credit: Bastian Asmus of http://en.archaeometallurgie.de/gossan-iron-cap/

Photo Credit: Reich, M. et al., 2009
Discussion: Talcuna Mine

- Host Rock
  - Barite
  - Chlorite
  - Epidote
  - Albite (vein)
  - **Greenschist Facies** (Wilson, 2016)

- Ore Material
  - Bornite
  - Galena
### Discussion: Montecristo

- **Magnetite**
- **Chalcopyrite**
- **Edenite**
- **Quartz**

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Conclusion

**Michael**
- Sulphide ore mineral was generally replaced by Copper Chloride atacamite within the past 2 million years

**Joel**
- Low grade metamorphism
- Greenschist Facies
- Ore: Bornite

**Joey**
- Ore: Magnetite, Chalcopyrite and Edenite
- From the Montecristo vein
Acknowledgements

- The assistance of Dr. Eidukat for sample preparation and project guidance
- Dr. Hopkins for providing access to the thin section equipment
- Jackie Wrage
- Research 2 for XRD
- NDSU electron microscopy center
References


References


Works Cited

- Eion M. Cameron, Palacios, Matthew I. Leybourne, 2006, Atacamite in the oxide zone of copper deposits in northern Chile: involvement of deep formation waters? Miner Deposita (2007) 42:205-218, Received: 12 October 2006 /Accepted: 21 October 2006 / Published online: 28 November 2006, https://doi.org/10.1007/s00126-006-0108-0