Timing of mineralization in the palm of your hand Cross-cutting relations, copper minerals and ore-forming hydrothermal fluid evolution

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Notes for the Instructor:

This lab accompanies lectures/classes in economic geology and ore mineralogy, either in a mineralogy or petrology course. It can also accompany studies of fluid rock interactions, fracture flow, fluid evolution, or geochemistry; or these topics be woven together using this lab as a base. This lab exercise also integrates previously learned material: cross-cutting relationships (Introductory Geology), with determination of mineralogy (Mineralogy), review of idochromatic elements producing color and their use in mineral identification (Mineralogy), chemistry of the fluids (Geochemistry), and changes in fluids with time during hydrothermal alteration events (Economic Geology). It also demonstrates the linkage between fluid composition, igneous petrology, ore geology and mineralogy.

This exercise can easily be increased in complexity or modified for level of difficulty, depending on what class level is being taught. For those students who have not yet had a full geochemistry class, activity-activity (a-a) diagrams provided can be briefly explained. The primary utility is that a-a diagrams show, one a single diagram, the fluid composition in equilibrium with the solid phases. (If you wish more info on this, please e-mail me). For more advanced students and students of geochemistry, students can be given appropriate thermodynamic data for the phases and asked to calculate and construct activity-activity diagrams for these phases. They can then plot the path that the mineralizing fluid must evolve along on the diagram (in addition to using the one diagram provided) to show the evolution of fluids.

I introduce this lab by discussing the importance of minerals that accumulate into ore-deposits and the necessity of those minerals to our standard of living. This can also be integrated with topics such as sustainable environments. In addition, this lab serves to discuss the role of hydrothermal fluids associated with igneous activity, fluid evolution with time and the role of flow through fractures.

A different slab is given to each small group of students (or they can work individually). Students can be given a single slab to decipher, or all of the slabs. The lab concludes with an in-class comparison of the different geologic histories obtained from the different slabs or the different groups or students working on the same slab. This also provides an overview of heterogeneities and variability in seemingly similar systems.

Materials:

Slabs of hydrothermally altered igneous rock, cut by numerous Cu-bearing mineral veins, or scans of these slabs (see attached images or
http://www.geol.lsu.edu/dutrow/mingy/cu_min_slabs.html)
that can be used in lieu of actual materials. NOTE: If you want to print color images from a pdf file, you must set it to postscript level two or three.

The slabs are from Morenci and Bisbee, AZ. I purchased these slabs from: Midwest Minerals and Mining, 1301 W. Kilburn, Tucson, AZ 85705. (The owner of the store has his BS in Geology from Ohio State and is thrilled when "real" geologists want rocks from him!) He exhibits at the Tucson Gem and Mineral Show each year, in the Desert Marketplace on Oracle Rd.

Activity - Activity diagrams are provided for use. If you work with advanced students, thermodynamic data for the phases of interest is needed (from SUPCRT or your favorite thermo database or from Woods and Garrels, 1986) if you wish the students to calculate the diagrams. Also, if you have an activity-activity (a-a) diagram code you can use that makes plotting easier. Alternatively, students can draw a-a diagrams by hand.

Answer Key:

1., 2., 3.,

The cross-cutting relationships can be difficult to access. I place less emphasis on these, and more on determining the mineralogy and changing composition of the mineralizing fluid. Most of these minerals are characterized by bright colors and can be easily identified by color alone. One can tell the students that these minerals contain Cu, although it is not necessary. The grey/black mineral in all of these is chalcocite. In most slabs, there is some combination of azurite, malachite, cuprite, chalcocite, and/or native Cu plus clays and quartz in the matrix. The single sample from Bisbee contains chrysocolla, the light blue mineral and shows how secondary minerals can also be altered.

Red, Cuprite, Cu_2O

Green, Malachite, $Cu_2CO_3(OH)_2$

Blue, Azurite, $Cu_3(CO_3)_2(OH)_2$

Grey, Chalcocite, Cu_2S

Copper, Native Copper, Cu

Light Blue, Chrysocolla, $Cu_4H_4Si_4O_{10}(OH)_8$ (or some variant thereof).

Matrix: Quartz, Clays (I need to xray)

Brochantite, $Cu_4SO_4(OH)_6$ (on activity - activity diagram)

Chalcanthite, $CuSO_4 \cdot 5H_2O$ (on activity - activity diagram)

Antlerite, $Cu_3SO_4(OH)_4$ (on activity - activity diagram)

Paratacamite, $Cu_2(OH)_3Cl$ (on activity - activity diagram)

Tenorite, CuO, (on activity-activity diagrams)

4. See above.

   We can use color to identify these minerals because the chromophore is an element essential to the mineral structure. (Idochromatic).

5. For example:

Relative Age	Color	Mineral	Formula	% Cu	Cu State	Fluid Compo
Oldest						
Matrix						
Generation 1	Red	Cuprite	Cu_2O		Cu^{+1}	Cu, oxidizing

6. Secondary minerals that form in the oxidized zone of copper deposits.

7. Examining the copper content of the minerals and the activity - activity diagrams provides information on changing fluid compositions. Three a-a diagrams are given. For example using these diagrams to describe the alteration/weathering of chalcocite to native copper, Cu-sulfates and Cu-carbonates, can be briefly summarized as follows. Decreasing the $P_{(CO_2)}$ or Cu activity, or increasing the activity of the hydrogen ion, will cause solutions to move from the equilibrium stability field of azurite to malachite (or vise versa). To move from chalcocite to copper, solutions can increase in the activity of Cu, or decrease in activity of H. To move from chalcocite to the carbonates or sulfates requires more oxidizing conditions. Hydrolysis reactions can be written for the phases of choice.

8. Geologic history can be more or less involved. Intrusion of igneous magma, rich in Cu. Exsolution of Cu-bearing fluids, probably in reduced environment fracturing of rock. Fluids flow into the fractures, crystallize (probably a reducing environment, depending on if chalcocite is oldest). Uplift and secondary alteration in oxidized zone. Fluid infiltration. The change in the fluid composition depends on the mineralogy from oldest to youngest.