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## **ENVIRONMENTAL BEHAVIOR OF SEVERAL PORPHYRY MOLYBDENUM AND COPPER DEPOSITS IN THE WESTERN US**

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### Introduction-

Weathering of mineral deposits imparts a chemical signature on ground and surface water. Which elements are enriched in natural waters depends on the mineral deposit type, host-rock lithology, ore and gangue mineral assemblage, and environment (climate and hydrologic setting). Ongoing research at the US Geological Survey (USGS) is attempting to classify the environmental behavior of various mineral-deposit types, including Mo and Cu porphyry deposits. Our goal is to develop a database that will facilitate a predictive capability for the environmental behavior of as-yet-undiscovered mineral deposits, help constrain pre-mining geochemical baselines in areas where no information exists, provide information related to water-quality standards, aid in mitigation and remediation strategies, and other purposes. This paper discusses some of the element signatures found in surface or ground water samples collected near a number of porphyry deposits in the western US, and describes ways of characterizing the deposits and distinguishing them from local or regional baseline values.

At present, the economically most important sources of copper and molybdenum are found in porphyritic igneous intrusions, known as porphyry copper-molybdenum (Mo/Cu  $\leq 0.1$ ), porphyry molybdenum-copper (Mo/Cu 1–0.1), and porphyry molybdenum deposits (Mo/Cu  $>1$ ) [1]. The first two types typically form in association with subduction-related, tholeiitic to calc-alkalic batholiths. The third type occurs in similar tectonic terranes, but is related to melts generated during gravitational collapse of tectonically overthickened crust. The third type is characterized by highly evolved granite intrusions enriched in large-ion-lithophile elements (Zr, Nb, Mo, Ta, Sn, Cs, W, Th, U), high-field-strength elements (Zr, Ti, Nb, Ta), and light rare-earth elements (Ce, Pr, Nd, Sm). The third type also contains higher concentrations of fluorine relative to the first two types. All deposits sampled in this study (Table 1) were unmined and minimally disturbed, but all have been prospected or drilled. Therefore, this sample suite provides an example of pre-mining conditions for these deposit types.

The intrusive rocks that host these porphyry deposits, as well as the surrounding alteration zones, have a geochemical weathering signature that is often distinct from that of the original country rocks. One strategy in determining the spatial extent of the geochemical signature of porphyry deposits is to examine in detail the elements that are enriched in the deposits compared to surrounding rocks, and then to see to what extent those elements are found in surface or ground water near the deposit. However, because not all elements have the same geochemical mobility, the spatial extent of any geochemical anomaly may vary depending on which elements are used to define the anomaly.

Aqueous Geochemical Signatures of Porphyry Deposits-

Major-element chemistry of waters draining the deposits is shown in a Piper diagram in figure 1. The cation composition of the waters is generally dominated by Ca or Mg, but the samples from Buckingham and Humboldt have significant sodium. For most of the deposits, sulfate is the dominant anion, although the effect of limestone host rock is seen on the Cannivan Gulch deposit, with high total CO<sub>3</sub>, Ca and Mg concentrations. For each of the deposits shown on the Piper plot, many other samples were collected in the same area. When water samples from each deposit are compared to the greater population of samples from the area, mixing lines may be observed that illustrate the effect of the porphyry deposit on the regional water quality. Figure 2 shows the cation field of the Piper plot for the Redwell Basin study area. The most upstream sample is in the lower left portion of the field, and water compositions evolve away from the Ca endmember (along arrow 1) as mixing with porphyry drainage waters occurs. Further downstream, Redwell Creek mixes with drainage from the Daisy Mine, a Pb-Zn-Cu vein deposit. From there, water compositions evolve slightly along a second mixing line (arrow 2) as Daisy Mine water is added to the much greater flow of Redwell Creek.

Another distinguishing feature of some porphyry deposits is that they are typically enriched in

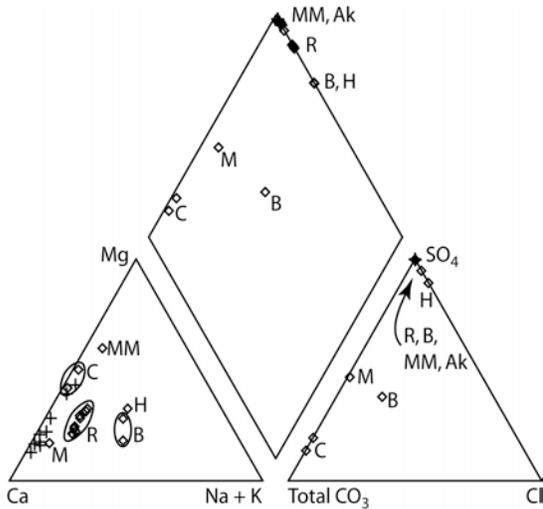


Figure 1- Piper trilinear diagram for water samples from deposits listed in Table 1. The letters refer to the locations listed in the first column of table 1.

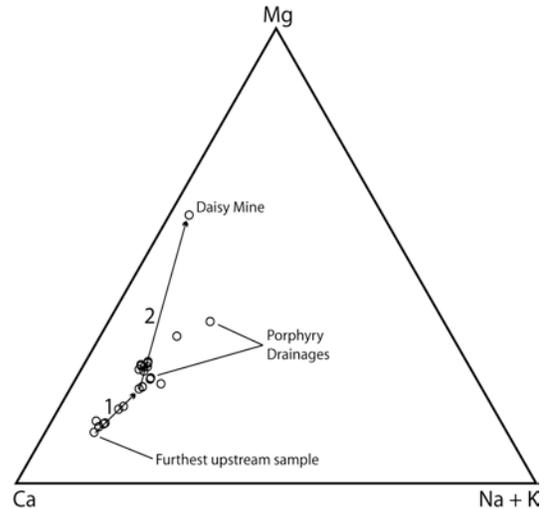


Figure 2- The cation field of the Piper plot for the Redwell Basin, western Colorado, USA. Mixing relations discussed in the text are show as arrows labeled 1 and 2.

Table 1- deposits sampled for this study. Letters in brackets {} refer to locations in figure 1.

Deposit name	Location	Characteristics
Redwell Basin {R}	Western Colorado	Climax-type porphyry Mo deposit- associated with high-silica rhyolite intrusion [2].
Mount Moly {MM}	Southwest Colorado	Porphyry Mo-Cu- associated with granodiorite and quartz monzonite [3].
Bond Creek {Ak}	Southern Alaska	Porphyry Cu-Mo- associated with quartz-diorite to granodioritic rocks [4].
Orange Hill {Ak}	Southern Alaska	Similar to Bond Creek [4].
Buckingham {B}	Northern Nevada	Porphyry Mo-Cu- associated with granodiorite and quartz monzonite.
Humboldt Canyon {H}	Southern Arizona	Porphyry Cu-Mo- associated with quartz-diorite to granodiorite.
Margaret {M}	Southwest Washington	Porphyry Cu-Mo- associated with quartz-diorite to granodiorite.
Cannivan Gulch {C}	Southwest Montana	Porphyry Mo-Cu- associated with granodiorite and granite.

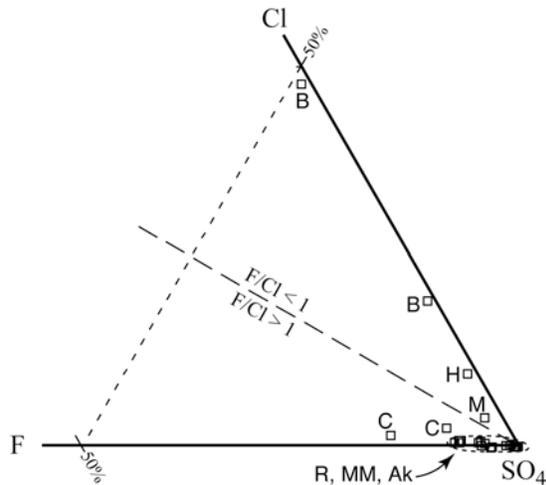


Figure 3- Deposit drainages show variations in F-Cl-SO<sub>4</sub> ratios that are related to chemistry of host-rocks.

fluorine. Common mineral hosts for fluorine include fluorite (CaF<sub>2</sub>), topaz (Al<sub>2</sub>SiO<sub>4</sub>(F,OH)<sub>2</sub>), and micas (e.g., annite, KFe<sub>3</sub>AlSi<sub>3</sub>O<sub>10</sub>(OH,F)<sub>2</sub>). The weathering of these minerals provides a steady release of fluorine from the deposits [5]. Figure 3 shows the molar proportions of F<sup>-</sup>, Cl<sup>-</sup>, and SO<sub>4</sub><sup>2-</sup> in waters draining the deposits. Note that the figure shows only about a fourth of the ternary diagram, so SO<sub>4</sub><sup>2-</sup> dominates the anionic composition of these waters, as expected for weathering of deposits rich in sulfide minerals. The porphyry Cu and Cu-Mo deposits from Nevada,

Arizona and Washington have generally lower F/Cl ratios, while the remaining deposits (Mo and Mo-Cu) have generally higher F/Cl, similar to the ratios seen in the deposits. The Alaska deposits (Cu-Mo) have

moderate to high F/Cl ratios, which matches leach experiments of rocks from those deposits [4].

Drainages from the porphyry deposits commonly have concentrations of Al, Cd, Cu, Fe, Mn, Pb, and Zn that exceed US drinking-water limits [6], although deposit drainages are not required to conform to these limits in the US. Chronic and acute aquatic life standards, adjusted for water hardness, also are commonly exceeded for Cd, Cu, Pb, and Zn. Further toxicity studies are needed to confirm any adverse effects on biota.

#### Summary-

Current research at USGS is attempting to characterize the environmental geochemistry of mineral deposits of various types, including porphyry deposits. A preliminary comparison of the aqueous geochemical signatures of the deposits is presented in this report. The aqueous geochemical signatures of the deposits can be distinguished based on a number of chemical parameters, which correlate to properties of the host rocks or surrounding altered rocks. These chemical distinctions also help to differentiate between environmental effects of the mineral deposits and regional geochemistry.

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