

# Phanerozoic Iron-Oxide (-REE-Cu-Au-U) Systems in Southwestern North America and Their Origins

Mark D. Barton, David A. Johnson,  
and Lukas Zürcher

Center for Mineral Resources  
Department of Geosciences  
University of Arizona  
Tucson, Arizona 85721  
barton@geo.arizona.edu

Hydrothermal iron-oxide-rich mineralization (analogous to Kiruna / Olympic Dam types) is widespread in southwestern North America. Collectively these occurrences form a metallogenic province comparable in number and area to better known Proterozoic and Phanerozoic provinces elsewhere (Figure 1). Varied in detail, these deposits share an association with saline fluids, voluminous alkaline (Na- and/or K-rich) alteration, low total sulfur contents, and variable enrichments in REE, Cu, Au, Ag, Co and U among elements of economic interest. Iron has been the major commodity produced with minor Cu and Au. Only iron is well documented. The largest systems contain on the order of 1Gt of iron-oxide-rich material (Humboldt Complex, NV; Yerington district, NV; Eagle-Palen Mountains, CA). The largest described Cu-rich portions of these systems have >10Mt of material containing in excess of 1% Cu and 0.1ppm Au. Massive (discordant to concordant), breccia and stockwork bodies of magnetite and/or hematite along with accessory phosphates, sulfides and silicates form the mineralized zones. Most metals are concentrated in the late / distal parts of the paragenesis. Study in this area offers a number of advantages: relative youth and good regional geologic control, diverse geologic settings, excellent exposures (commonly of tilted crustal sections), and previous study on a number of districts.

in M.D. Roberts and M.C. Fairclough (editors) Fe-oxide-Cu-Au Deposits: A discussion of critical issues and current developments, EGRU Contribution 58, James Cook University, p. 5-11. Presented March 17, 2000.

Most of these systems are closely related in time and space to magmatism, yet igneous compositions vary from mafic to felsic and from subalkaline to mildly alkaline. Hematite-rich detachment-type mineralization of the southern Basin and Range Province represents a variant that is possibly amagmatic in origin (Spencer and Welty, 1989; Wilkins et al., 1986; Chapin and Lindley, 1986). Structural controls on deposits are prominent, but the types of structures are highly varied including regional strike-slip, thrust, low-angle normal (“detachment”) and high angle normal faults, as well as igneous structures such as caldera-bounding faults, extensional dike swarms, and structures accommodating pluton emplacement.

Alteration and metal suites vary with composition of the host and associated igneous rocks. In feldspathic host rocks, sodic alteration (albitization, scapolitization) is deep whereas hydrolytic alteration (sericitic, chloritic and local advanced argillic assemblages) is shallow. Details of the alteration assemblages vary with host composition (mafic to felsic, carbonate) and also with inferred sources of hydrothermal fluids (magmatic, marine evaporitic, continental evaporitic). An association of sodic alteration and porphyry copper systems is well documented in the Yerington district, Nevada and elsewhere (Carten, 1986; Dilles and Proffett, 1995), however sodic alteration is far more

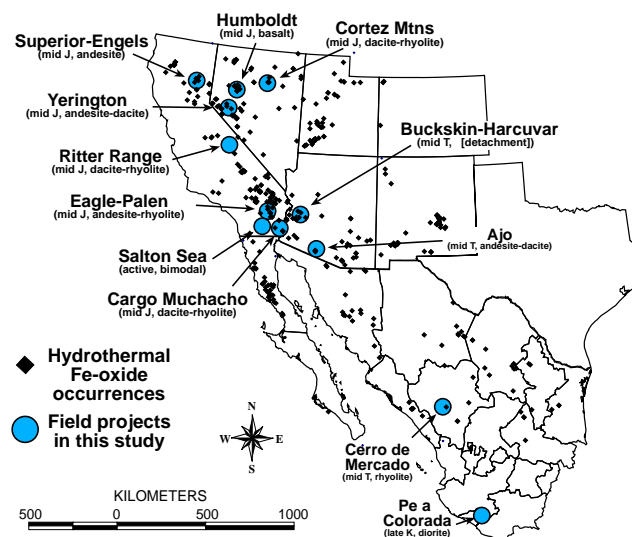


Figure 1. Distribution of Fe-oxide-rich hydrothermal systems of Phanerozoic age in southwestern North America. Most belong to one of three episodes: Jurassic (western U.S., northern Mexico), Laramide (Late Cretaceous - Paleocene; western Mexico), Oligocene-Early Miocene (central Mexico to southwestern U.S.). Names, ages, and associated igneous rock types are shown for selected districts that have been studied in this project.

widespread and the characteristic type of associated mineralization is iron-oxide-rich and not porphyry style (Barton et al., 1988; Battles, 1990; Battles and Barton, 1995). Where present, potassic alteration associations (K-feldspar, K-mica) are typically shallow and constitute two distinct types: one where fluids upwell (and can deposit ore minerals), the other where alkaline fluids recharge. These two are distinguishable in geometry (vertically focused vs. laterally extensive), mineral associations (Kf-Bi-Qz-sulfides vs. Kf-Hm), and geochemistry (e.g.,  $\delta^{18}\text{O}$ , T of formation). Calcic minerals, notably actinolite and clinopyroxene can be common with both sodic and potassic assemblages. In southwestern North America, an abundance of carbonate host rocks leads to widespread development calcisilicate (skarn) alteration assemblages. In a number of districts the skarns are clearly lateral variations of igneous-hosted Fe-oxide types.

Most Phanerozoic systems in SWNA belong to one of three episodes (Table 1). In the U.S., Jurassic and mid-Tertiary ages predominate, whereas in Mexico mid-Tertiary and Laramide systems are most common. The active Salton Sea geothermal system provides a useful modern analog (McKibben and Hardie, 1997). These and other geologic patterns coupled with petrochemical evidence (petrological, whole rock, isotopic, theoretical) suggest a central role in many systems for an evaporitic component from contemporaneous/older brines or evaporites (cf. Barton and Johnson, 1996; Battles and Barton, 1995). Some systems (e.g., Yerington batholith, Yerington district, NV; Carten, 1986; Dilles and Einaudi, 1992) are clearly hybrids of magmatic-hydrothermal systems with non-magmatic brines. In others (e.g., Humboldt mafic complex, NV, Vanko and Bishop, 1982; Battles, 1990; Shamrock batholith, Yerington district, NV, Battles, 1990; detachment systems, AZ-CA, Wilkins et al., 1986; Spencer and Welty, 1989) a magmatic fluid component is absent likely absent. A few systems (e.g., Superior-Engels, CA) could be largely magmatic-hydrothermal, however, even there evidence is equivocal. Most metals are from igneous rocks, but may not be sourced from a magma. Rather, whole rock compositions, other geochemical evidence (isotopes) and field relationships indicate that metals are stripped during sodic and other types of alteration, commonly in world class amounts ( $\text{Fe} > 1\text{Gt}$ ,  $\text{Cu} > 10\text{Mt}$ ,  $\text{Zn} > 10\text{Mt}$ ).

Theoretical modeling of the saline non-magmatic fluids in igneous-related hydrothermal systems provides a test for what can happen in this geologically plausible environment. We have

considered energy and mass balance constraints on the involvement of non-magmatic brines in igneous-driven hydrothermal systems (Barton et al., 1998). From this we predict similarities and differences with systems where fluids are derived from magmatic sources. Simulations (based on modified numerical models from Hanson, 1995; Hanson et al., 1993) allow further analysis, particularly of impact of alternative geometries, permeability structures, and chemical feedbacks. This coupled physical and chemical approach allows a parametric analysis of the similarities and differences in hydrothermal alteration, metal sources, and possible traps. Theoretically, multiple mechanisms can be effective in precipitating metals of economic interest, thus the rarity of economically mineralized systems compared to the large number of occurrences suggests that geological serendipity plays a larger role than in some other deposit types.

In comparison with porphyry-style mineralization from the same size and composition intrusion, circulation of externally-derived brines creates much more voluminous alkali alteration with different geometries. Absolute metal mobilities are potentially greater, but the total masses concentrated are sensitive to (and typically limited by) the original bulk contents and availability of appropriate traps. The models predict metal contents and alteration volumes compatible with system-scale observations. Both end member and hybrid systems (magmatic and non-magmatic sources) seem likely. In principle, both can produce significant Cu mineralization ( $>1\text{ Mt}$  contained Cu).

Evaluation of alternative models for Fe-oxide-rich systems can be systematically tested by modeling, but it must be founded on field-based geological understanding of the spectrum of known systems. It is unlikely that any single model will explain the diversity of these metal-enriched iron-oxide dominated rocks. Critical issues are to better understand the distribution of alteration and its links to metals, the fate of precious metals and base metals in sulfur-deficient systems, the meaning of differences in tectonic, magmatic and sedimentary settings among the systems, and the significance of alternative origins for economic potential.

**Table 1.** Some characteristics of Phanerozoic Fe-oxide(-REE-Cu-Au etc.) systems from southwestern North America

Selected Regions	Age	General geology	Hydrothermal features	Key examples	Comments	References
Salton Trough, southern California	modern	northernmost spreading segment of E Pacific Rise, flooded by evaporite-rich sediments from the Colorado River delta	saline (TDS ~ 25 wt % NaCl) & metal-rich hydrothermal systems; alteration, veins & flashing products all parallel ancient examples	Salton Sea, CA (oxidized); Brawley, CA (reduced); Cerro Prieto, BCN (fresh)	several styles of geothermal systems ranging from saline to dilute	McKibben and Hardie, 1997
Mexican Altiplano (Durango, Chihuahua, Coahuila, Sonora)	mid-Tertiary	subalkaline to marginally alkaline magmas emplaced through Mesozoic rift basin / carbonate platform	Hm-Mt-Ap dominated deposits with sulfates & Na±K alteration; locally hydrothermal syngenetic	Cerro de Mercado, DUR; La Perla, CHIH	examples found north into Utah and Colorado	Lyons, 1988; Barton et al., 1995
southern Basin & Range (Arizona, southern California)	mid-Tertiary	major extensional province with broadly coeval volcanism and formation of evaporite-bearing basins	K-altered upper plate rocks, Hm-Cu-Au ores near detachment faults; poorly known deep Na-rich	Buckskin-Harcuvar-Whipple core complex, CA-AZ; Ajo, AZ	may have parallels in lower salinity systems to the north	Spencer and Welty, 1989; Wilkins et al., 1986; Chapin et al., 1986
western Mexico (locally including Arizona & New Mexico)	Late Cretaceous - Early Tertiary	subalkaline arc developed in accreted terranes with Mesozoic evaporite-rich overlap sequence	Mt±Hm rich skarns and breccias with variable amounts of Cu, Co, Au, U	Pena Colorada, COL; San Antonio de la Huerta, SON	Laramide arc contains many porphyry Cu-Mo-Au prospects and some major districts; Fe-oxide systems commonly separate	Zurcher, 1994; Barton et al., 1995
Great Basin - Mojave (Nevada, California, Arizona)	Jurassic	long-lived arc in notably arid environment; subalkaline to mildly alkaline magmas along trans-tensional to transpressional margin	iron-oxide-rich systems with abun. sodic alteration clearly associated with external brines; variability in metal contents, K contents and styles	Humboldt mafic complex, NV, Yerington, NV; Cortez Mountains, NV; Eagle Mountain, CA	part of larger province extending from north-central Mexico possibly into transported terranes of Canadian Cordillera	Carten, 1986; Dilles and Einaudi, 1992; Battles and Barton, 1995; Barton et al., 1988; Vanko and Bishop, 1982

## References

- Barton, M. D., Battles, D. A., Bebout, G. E., Capo, R. C., Christensen, J. N., Davis, S. R., Hanson, R. B., Michelsen, C. J., and Trim, H. E., 1988, Mesozoic contact metamorphism in the western United States, in W.G. Ernst, ed., *Metamorphism and Crustal Evolution, Western Conterminous United States: Rubey Volume VII*, Prentice-Hall, Englewood Cliffs, New Jersey, p. 110-178.
- Barton, M. D., and Johnson, D. A., 1996, Evaporitic-source model for igneous-related Fe oxide-(REE-Cu-Au-U) mineralization: *Geology*, v. 24, p. 259-262.
- Barton, M. D., Johnson, D. A., and Hanson, R. B., 1998, Evaluation of possible roles of non-magmatic brines in igneous-related hydrothermal especially Fe(-Cu-Au-REE) deposits: *Geological Society of America Abstracts with Programs*, v. 30(7), p. 127.
- Barton, M.D., Staude, J.-M.G., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico: *Bootprints Volume, Arizona Geological Society Digest v. 20*, 487-524.
- Battles, D. A., 1990, The hydrothermal evolution of the Shamrock Batholith, western Nevada, and the origin of sodium-rich alteration in the western United States: unpublished Ph.D. thesis, University of California, Los Angeles, 122 p.
- Battles, D. A., and Barton, M. D., 1995, Arc-related sodic hydrothermal alteration in the western U. S.: *Geology*, v. 23, p. 913-916.
- Carten, R. B., 1986, Sodium-calcium metasomatism; chemical, temporal, and spatial relationships at the Yerington, Nevada, porphyry copper deposit: *Economic Geology*, v. 81, p. 1495-1519.
- Chapin, C. E., and Lindley, J. I., 1986, Potassium metasomatism of igneous and sedimentary rocks in detachment terranes and other sedimentary basins; economic implications: *Arizona Geological Society Digest*, v. 16, p. 118-126.
- Dilles, J. H., and Proffett, J. M., 1995, Metallogensis of the Yerington batholith, Nevada: *Arizona Geological Society Digest*, v. 20, p. 306-315.
- Dilles, J. H., and Einaudi, M. T., 1992, Wall-rock alteration and hydrothermal flow paths about the Ann-Mason porphyry copper deposit, Nevada; a 6-km vertical reconstruction: *Economic Geology*, v. 87, p. 1963-2001.
- Hanson, R. B., 1995, The hydrodynamics of contact metamorphism: *Geological Society of America Bulletin*, v. 107, p. 595-611.
- Hanson, R. B., Sorensen, S. S., Barton, M. D., and Fiske, R. S., 1993, Long-term evolution of fluid-rock interactions in magmatic arcs: Evidence from the Ritter Range pendant, Sierra Nevada, California, and numerical modeling: *Journal of Petrology*, v. 34, p. 23-62.
- Hitzman, M. W., Oreskes, N., and Einaudi, M. T., 1992, Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits: *Precambrian Research*, v. 58, p. 241-287.
- Lyons, J. I., 1988, Volcanogenic iron oxide deposits, Cerro de Mercado and vicinity, Durango, Mexico: *Economic Geology*, v. 83, p. 1886-1906.
- McKibben, M. A., and Hardie, L. A., 1997, Ore-forming brines in active continental rifts, in Barnes, H. L., ed., *Geochemistry of Hydrothermal Ore Deposits*, John Wiley and Sons, p. 877-936.
- Spencer, J. E., and Welty, J. W., 1989, Mid-Tertiary ore deposits in Arizona: *Arizona Geological Society Digest*, v. 17, p. 585-607.
- Vanko, D. A., and Bishop, F. C., 1982, Occurrence and origin of marialitic scapolite in the Humboldt Lopolith, N.W. Nevada: *Contributions to Mineralogy and Petrology*, v. 81, p. 277-289.
- Wilkins, J. J., Beane, R. E., and Heidrick, T. L., 1986, Mineralization related to detachment faults; a model: *Arizona Geological Society Digest*, v. 16, p. 108-117.
- Zürcher, L., 1994, Paragenesis, Elemental Distribution, and Stable Isotopes at the Peña Colorada Iron Skarn, Colima, Mexico: Unpublished