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Metal Concentrations in Crustal Fluids and Their Relationship to Ore Formation

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Abstract

A database of saline fluid compositions, including deep shield ground waters, sedimentary formation waters, geothermal brines, and fluids from metamorphic and igneous rocks and veins, is used to explore the controls on metal concentrations in crustal fluids. There are no systematic differences between analyses of fluids sampled by drilling and analyses of fluid inclusions. Over the wide range studied, temperature emerges as a dominant control on the concentrations of Fe, Mn, Zn, and Pb in solution, although the more limited data for Cu are equivocal. Chloride concentration is also important, with the mole ratio metal/chloride (Me/Cl) remaining reasonably constant at constant temperature over a wide range of chlorinities for all four metals considered in detail. There is no evidence for significant differences in transition-metal speciation with increasing chloride nor between low- and high-temperature fluids, although in the case of Zn, complexes with additional Cl may be important at low temperature. Plots of log Me/Cl versus 1/T for the transition metals considered each yield a linear correlation, with about five orders of magnitude variation in Me/Cl between diagenetic and magmatic temperatures. There is approximately two orders of magnitude variability at each temperature, which probably arises in large part from variations in pH. Limited data for low-salinity, CO_2-rich fluids indicate that they lie on the same trends, with transition-metal concentrations controlled by fluid salinity and temperature. Order of magnitude concentrations of Fe, Mn, Zn, and Pb in any chloride-dominated crustal fluid can be predicted with the following equations (T in K, concentration ratios are molar): $\log (Fe/Cl) = 1.4 - (1,943/T) \pm 1$; $\log (Mn/Cl) = 0.55 - (1,871/T) \pm 1$; $\log (Zn/Cl) = -(1,781/T) \pm 1$; $\log (Pb/Cl) = -1.2 - (1,533/T) \pm 1$.

The results demonstrate that crustal fluids are strongly buffered through interactions with the rocks (or melts) that host them. Thus, of the major variables influencing metal concentrations in solution, only temperature and chloride concentration can be considered as truly independent. The plots show that metal-rich fluids may arise through equilibration of chloride-rich waters with normal silicate rocks. Saline magmatic fluids, which may attain extremely high concentrations of transition metals, have clear ore-forming potential, as do formation brines from deep, hot basins; cooler basins do not permit such high concentrations of base metals to be attained. The results of this study emphasize the importance of the distribution and cycling of chloride in the crust for the distribution of base metal deposits; it is often the salinity of ore fluids that is the primary anomaly.

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