Cu and Fe diffusion in rhyolitic melts during chalcocite “dissolution”: Implications for porphyry ore deposits and tektites

PENG NI1,*, YOUXUE ZHANG1, ADAM SIMON1, and JOEL GAGNON2

1Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, Michigan 48109, U.S.A.
2Department of Earth and Environmental Sciences, University of Windsor, Windsor, Ontario N9B 3P4, Canada

ABSTRACT

Copper diffusion plays an important role in natural processes, such as metal transport during the formation of magmatic-hydrothermal porphyry-type ore deposits and Cu isotope fractionation during tektite formation. Copper diffusion data in natural silicate melts, however, are limited. In this study, chalcocite (Cu2S) “dissolution” experiments were carried out using chalcocite-rhyolite diffusion “couples” to study Cu (and S) diffusion in rhyolitic melts. Instead of chalcocite dissolution as initially expected, our experiments show that Cu is transferred from the chalcocite crystal to the rhyolitic melt, and Fe is transferred from the rhyolitic melt to chalcocite, whereas the S concentration profile in the rhyolitic melt is essentially flat. From the Cu and Fe exchange profiles in the rhyolitic melts, Cu diffusivities and Fe diffusivities are obtained and reported. Copper diffusion in rhyolitic melts containing 0.10 to 5.95 wt% H2O at temperatures of 750 to 1391 °C and pressures of 0.5 to 1.0 GPa can be described as:

\[ D_{Cu}^{\text{rhy}} = \exp \left[ -14.75 \pm 0.35 - (0.23 \pm 0.10)w - \frac{(11647 \pm 491) - (698 \pm 117)w}{T} \right], \]

which allows the estimation of an activation energy for diffusion in dry rhyolitic melts to be 96.8 ± 4.1 kJ/mol. In the above equation, diffusivity (\(D\)) is in m²/s, \(T\) is the temperature in K, \(w\) is the H₂O concentration in the rhyolitic melts in wt% and all errors reported are at 1σ level. Combining Cu diffusion data from this study and previous data in basaltic melt gives a general equation for Cu diffusivity in natural silicate melts:

\[ D_{Cu} = \exp \left[ -17.3 \pm 0.9 + (3.8 \pm 1.5)(\text{Si+Al-H}) - \frac{(4403 \pm 1094) + (9700 \pm 1921)(\text{Si+Al-H})}{T} \right], \]

where Si+Al-H is the cation mole fraction of Si plus Al minus H in the silicate melt on a wet basis. Iron diffusivities obtained in this study, in anhydrous to 6 wt% H₂O rhyolite, are combined with previous data to get a general equation for Fe diffusion in rhyolitic melts:

\[ D_{Fe}^{\text{rhy}} = \exp \left[ -16.1 \pm 1.7 - \frac{(19859 \pm 2541) - (1218 \pm 135)w}{T} \right]. \]

Our data demonstrate that Cu diffusion is faster than H₂O or Cl in rhyolitic melts containing 6 wt% water, which indicates that the scavenging and transport of Cu by a magmatic volatile phase during formation of porphyry-type ore deposits is not limited by diffusion of Cu. Based on our experimental data, Cu diffusivity is almost four orders of magnitude higher than Zn in anhydrous rhyolitic melts, which supports the explanation of more diffusive loss of Cu leading to more fractionated Cu isotopes than Zn isotopes in tektites.

Keywords: Copper diffusion, iron diffusion, porphyry-type deposits, kinetic fractionation

INTRODUCTION

Porphyry-type ore deposits are important sources for metals, such as Cu, Au, Mo, and Ag, comprising ~57, 10, 99, and 13%, respectively, of the world’s total discovered quantities of these metals (Singer 1995). To form a porphyry-Cu deposit, the Cu concentration must be enriched from a crustal average concentration of ~30 ppm (Rudnick and Gao 2014) to a typical mineable grade of ~0.2 to 2 wt% in the porphyry environment (Simon and Ripley 2011). This two to three orders of magnitude enrichment is accomplished by, among other things, the efficient scavenging of Cu by a magmatic volatile phase (MVP) exsolved from...