

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

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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 diffusivity 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:

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

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:

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

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:

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

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