Carbon diffusion in solid iron metal at conditions of the Earth's upper mantle

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Recent studies have discussed the presence of carbon as carbide (either liquid or solid) at conditions of the Earth's upper mantle. However, the stability of carbon as dissolved component in iron metal or as carbide phases in the Earth's interior would be mainly controlled by the local Fe(Ni)/C ratios. This implies that at low carbon contents (<50 ppm), representative of a C-depleted mantle source, the transport of carbon will likely occur by interstitial diffusion through the coexisting metal phase. To date, no data are available to determine the effect of pressure and temperature on carbon diffusion in iron metal. Therefore, we performed experiments to determine the diffusion coefficient of carbon in iron at high pressure and temperature.

Experiments were performed using multianvil device at pressures between 3 and 6 GPa and temperatures of 800-1200 °C. Glassy carbon with zero-porosity and a density of 1.5 g cm^{-3} was used as diffusant, directly in contact with pure iron rod of known thickness, loaded in a MgO capsule. FE-SEM was used for textural observation and accurate determination of the interface between layers, while concentration profiles were measured using the electron microprobe with an optimized standardization procedure including Fe standards with different carbon contents. The concentration profiles of carbon in iron were computed to determine the diffusion coefficients based on Fick's second law formulation assuming isotropic one dimension diffusion. The diffusivity coefficient for carbon in iron metal is $\sim 3x10^{-11}$ m^2s^{-1}, with an activation energy of ~62 kJ/mol, in agreement with previous experiments performed at ambient pressure. The activation volume determined from our experiments is $\sim 1.5x10^{-6}$ m^3/mol that is almost identical to the activation volume determined for other elements for which a similar diffusion mechanism in iron has been established.

The data will be used to derive a model for carbon transport within a metal-saturated upper mantle and to constrain the conditions for the stability of C-rich metal phases.