Experimental Studies of Equilibrium and Transport Phenomena in the Earth's Crust and Mantle

by

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An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the degree of

DOCTOR OF PHILOSOPHY

Major Subject: Geology

The original of the complete thesis is on file
In the Rensselaer Polytechnic Institute Library

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November 2007
(For Graduation December 2007)

ABSTRACT

This dissertation presents the results of several studies of equilibrium and kinetic processes operating in the Earth's crust and mantle that fall under the broad category of experimental trace element geochemistry.

Chapter 1 details the calibration of a refined rutile (TiO_2) solubility model for hydrous siliceous melts. TiO_2 solubility has been investigated at $P = 1$ GPa and $T = 650 - 1000^o C$ and has been modeled as a function of both temperature (T) and melt composition (FM), and can be expressed as: $\log(Ti, ppm) = 7.95 - 5305/T + 0.124FM$. Constraining TiO_2 activity in the absence of rutile is critical to Ti-thermometry of quartz and zircon, and the results of this study suggest $a_{TiO2} = 0.6$ as a plausible minimum for TiO_2 activity in typical felsic rocks.

Chapter 2 reveals an experimentally calibrated thermobarometer for Zr-in-sphene (titanite). Sphene is a common accessory mineral in igneous and metamorphic rocks. Sphene was synthesized in the presence of rutile, quartz and zircon at $P = 1.0 - 2.4$ GPa and $T = 800 - 1000^o C$. Results of these experiments yield a systematic relationship between P, T and Zr concentration in sphene: $\log(Zr, ppm) = 10.52 - 7708/T - 960\,P/T$. When applied to natural sphene grains of unknown origin or growth conditions, this thermobarometer has the potential to estimate temperatures with an approximate uncertainty of ±20°C over the temperature range of interest (600–1000°C).

Chapter 3 presents the first ever experimental data on grain-boundary diffusion of siderophile elements and carbon in periclase (MgO) and olivine ($Fo_{90}Fa_{10}$). Grain-boundary diffusivity was determined by quantifying the extent of alloying between initially pure 'source' and 'sink' materials separated by a wafer of polycrystalline periclase or olivine. These were annealed at $1100 - 1600^o C$ and $1.5 - 2.5$ GPa. Grain-boundary fluxes were calculated for Os, Ir, Re, Pt, Au, Ru, W, Rh, Cu, Co, Mo, and C. Computed diffusivities range up to 10^{-7} m^2 s^{-1} —fast enough to allow transport over geologically significant length scales (10s–100s km) over the age of the Earth, thus establishing grain boundary diffusion as a fast pathway for transport from the core through the mantle.