

P-T-t evolution of the Valhalla Complex, British Columbia, Canada

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Introduction

The Valhalla Complex is part of the Shuswap terrane in southeastern British Columbia and is comprised of Cretaceous to Eocene granitic gneisses and granites in addition to a paragneiss of uncertain age. The complex is bounded by the Valkyr shear zone and the Slocan Lake normal fault and experienced rapid tectonic unroofing during the Eocene (Carr *et al.*, 1987).

Paragenesis, P-T conditions and P-T path

The main assemblage in the pelitic paragneiss is garnet + biotite + sillimanite + K-feldspar + plagioclase + quartz + ilmenite rutile. Garnet is feebly zoned with rimward increases in Ca, Mn, Fe and Fe/(Fe + Mg), and a decrease in Mg. Zoning in Fe, Mg and Mn is smooth as a result of diffusion whereas Ca zoning is discontinuous as a result of garnet production by reaction (2) below and slower diffusion. Peak pressures from GASP, GPBQ and GRAIL barometry provide consistent values of 8–1 kbar at 800°C (Fig. 1). A peak temperature of 820–20°C is constrained by dehydration and vapor-absent melting reactions (T quoted at 8 kbar):

- (1) $Ms + Pl + Qtz = Sil + Kfs + Liquid$ (constrains $T > 700^{\circ}C$)
- (2) $Bt + Sil + Pl + Qtz = Grt + Kfs + Liquid$ (constrains $T > 750^{\circ}C$)
- (3) $Ms = Kfs + Crn + H_2O$ (constrains $T > 800^{\circ}C$)
- (4) $Bt + Qtz = Opx + Kfs + Liquid$ (constrains $T < 840^{\circ}C$)

The prograde P-T evolution is constrained by rare sodic plagioclase inclusions in garnet, which suggest either isobaric heating or minor decompression with heating to the peak conditions. The absence of early kyanite limits the amount of decompression to less than 2 kbar. The retrograde path was ≈ 15 bars/degree, inasmuch as plagioclase composition does not change appreciably during retrogression.

Geothermometry using Fe-Mg exchange between garnet and biotite cannot be used to infer peak temperatures because the a priori assumption

of equilibrium between any particular biotite and garnet pair is unjustified. For example, the range of garnet-biotite temperatures is 580 to 1051°C and the range of garnet core + matrix biotite temperatures is 730 to 1051°C. However, if the peak temperature is known, the array of apparent garnet-biotite temperatures can be used to infer a reaction history. The earliest, and least modified, biotites are found as inclusions in quartz and plagioclase and have the highest Ti contents (5–5.5 wt %). Progress of reaction (2) drives garnet + biotite to more Mg-rich compositions, leaving these biotites stranded as Fe-rich inclusions that yield apparent garnet core + inclusion temperatures of 870°C. Other high-Ti biotites ($TiO_2 > 5$ wt.%) are found as inclusions in garnet and yield apparent temperatures of 830 to 655°C, which are closure temperatures resulting from Fe-Mg exchange between garnet and biotite. The initial apparent temperature for these inclusions in garnet would have likely been $T \approx 870^{\circ}C$ and the smaller inclusion re-equilibrated to lower temperature. Following the metamorphic peak at $T \approx 820^{\circ}C$, minor back reaction of (2) or the similar reaction (5) $Bt + Sil + Pl + Qtz = Grt + Kfs + H_2O$ produced garnet rims and matrix biotites that have higher Fe/(Fe + Mg) than at the peak, and produced the observed garnet zoning and matrix biotite inhomogeneity in Fe/(Fe + Mg) and Ti. Garnet core + matrix biotite temperatures range from 800°C, which may reflect near peak equilibration, to 1050°C, which reflects biotites with higher Fe/Mg than 'peak' biotites. Thermodynamic modeling suggests that reaction (2) or (5) took place over a 25–100°C interval (depending on H_2O availability) with the net transfer reaction shutting down at approximately 700°C, consistent with the matrix biotite + garnet rim temperatures of 700–750°C. The maximum amount of water required is approximately 2 % volume, which may have exsolved from melts produced by (2) during crystallization.

Cooling rates

Apparent temperatures from biotite inclusions within garnet range from 750 to 580°C and there

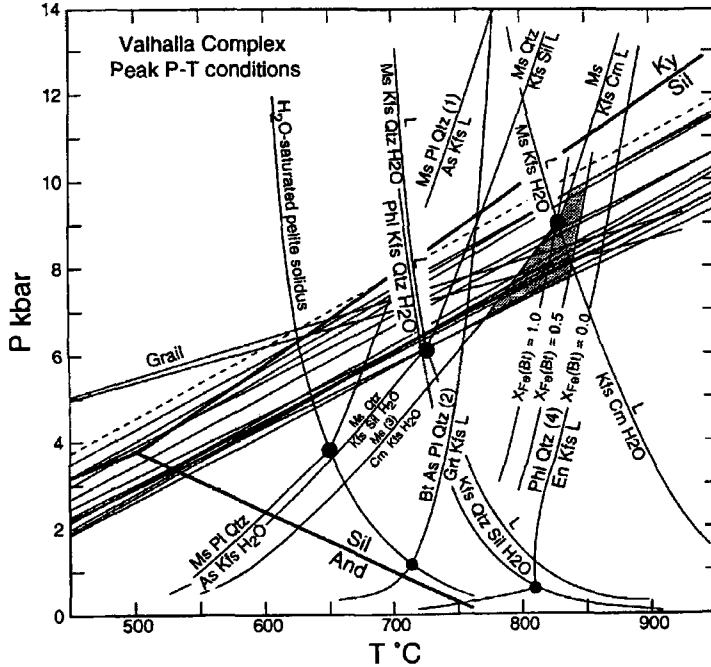


FIG. 1. P-T diagram showing constraints on the peak P-T conditions of the Valhalla Complex. Solid lines are GASP, GPBQ and GRAIL barometry. Melting and dehydration reactions from Huang and Wyllie (1974), Thompson and Tracy (1979), Berman (1988) and Vielzeuf and Clemens (1992).

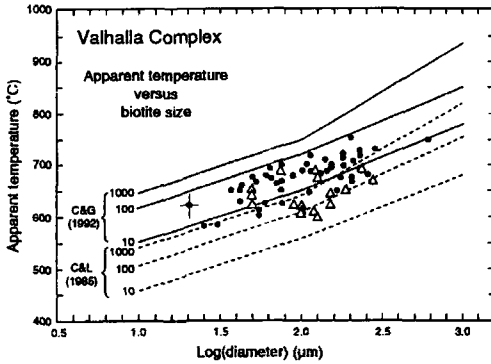


FIG. 2. Apparent temperature (garnet core + biotite) vs biotite size for biotite inclusions in garnet. Lines are from finite difference diffusion model: solid lines calculated using data of Chakraborty and Ganguly (1992); dashed lines using data of Cygan and Lasaga (1985). Circles are from samples V6 and V7 near the Valkyr shear zone; triangles are from sample V9 in the interior of the complex.

is a correlation between biotite size and temperature (Fig. 2), which has been modeled using diffusion theory to infer cooling rates. Using the tracer diffusion coefficients of Chakraborty and Ganguly (1992), samples from near the shear zone

(V6 and V7: dots in Fig. 2) are best modeled by a cooling rate of 10–100°C/Ma, which is in excellent agreement with the average cooling rate of 20°C/Ma determined from geochronology (Parrish, 1990). Use of Cygan and Lasaga (1985) tracer diffusivities for Mg requires a cooling rate in excess of 1000°C/Ma over the temperature interval of 820 to 600°C. As a cautionary note, ‘closure temperatures’ for garnet core + matrix biotite are spuriously high and give an incorrect estimate of cooling rate that is 1–2 orders of magnitude too high. It is essential that only Fe-Mg exchange be operative for this method to work.

Rocks from deeper in the complex (sample V9: triangles in Fig. 2) may have cooled more slowly than those from near the Valkyr shear zone which is to be expected if the heat sink is the hanging wall of the shear zone.

References

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