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Lawsonite eclogites from the Pinchi Lake area, British Columbia—new *P–T* estimates and interpretation

Edward Ghent [a,*], Douglas Tinkham [b], Robert Marr [a]

[a] Department of Geoscience, University of Calgary, Calgary, Alberta, Canada T2N 1N4
[b] Department of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada P3E 2C6

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ABSTRACT

Lawsonite eclogites from Pinchi Lake, British Columbia, occur as tectonic blocks associated with lawsonite, aragonite, and jadeite-bearing blueschists. One tectonic block from Tezzeron Lake shows extensive lower-temperature retrogression. The block from Beaver Lake Road (BLR) shows less retrogression and the garnet crystals contain abundant inclusions of lawsonite and omphacite suggesting these minerals were stable throughout most of the crystallization history. Compositional profiles and element maps of garnets show: (1) Mn enrichment in cores with decrease toward rims; (2) little change in Ca from core to rim; (3) general decrease in Fe/Mg from core to rim. Phase diagram sections for sample BLR-3 and garnet-core compositions suggest garnet-core growth at 505 °C and 24.3 kbar (1 kbar = 0.1 GPa). Temperature estimates based upon garnet–clinopyroxene Fe–Mg exchange geothermometry are, for inclusions in garnet at 25 kbar, 450 ± 30 °C (4 spots); 435 ± 15 (10); and 445 ± 25 (6). For garnet rims and matrix clinopyroxene the results are: 515 ± 50 °C (2); 440 ± 25 (5); 475 ± 20 (2). These results suggest very little if any statistically significant changes in temperature during crystal growth. Estimates of pressure are based upon several different calibrations of the garnet–clinopyroxene–phengite equilibria. Using the calibration of Krogh-Ravna we obtain pressures of: 24.2–26.8 kbar, compatible with that estimated for garnet-core growth in BLR-3. For the glaucophane = talc + jadeite geobarometer, the activity relations for glaucophane are not well constrained. At 450 °C a pressure of 26 kbar is calculated (one sample). A pressure of 25 kbar at 450 °C suggests depths of ~90 km, leading to a *P–T* gradient of ~5 °C km^{-1}. This gradient passes through the inferred stability field of lawsonite eclogites and the calculated stability fields of lawsonite for Pinchi Lake samples. This is very near the *P–T* stability field of coesite, which is characteristic of Ultra-High-Pressure metamorphism.

1. Introduction

Lawsonite eclogites have been proposed as a possible source of H_2O for arc magmatism in metamorphic rocks subducted to great depths, e.g., Connolly and Kerrick (2002). In addition, the presence of lawsonite eclogite has been used to explain seismic velocities in subducted slabs (Peacock and Wang, 1999). Evans (1990) presented thermodynamic models suggesting that lawsonite blueschists were favored at higher H_2O pressures and lower temperatures than epidote blueschists. Several papers have emphasized the rarity of lawsonite eclogite and the problems of their preservation, e.g., Ghent et al. (1993); Zack et al. (2004); Davis and Whitney (2006); Whitney and Davis (2006); Clarke et al. (2006); and Tsujimori et al. (2006).

In an earlier study Ghent et al. (1993) studied tectonic blocks of eclogite associated with lawsonite and aragonite-bearing blueschists along the Pinchi Fault Zone. They indicated that lawsonite appeared to be stable with omphacite and garnet in the Beaver Lake tectonic block (BLR, Fig. 1). The Tezzeron Lake eclogite (TZR, Fig. 1) contained lawsonite in the matrix but showed extensive retrogression.

These tectonic blocks occur as isolated blocks sitting on top of recent sediments, including glacial drift (Ghent et al., 1993). The tectonic blocks are clearly exotic. The eclogite tectonic blocks and the blueschists share similar $^{40}Ar/^{39}Ar$ cooling ages on phengite (Ghent et al., 1996). These cooling ages are near 220 Ma for both the tectonic blocks and the blueschists. The blueschists contain metamorphic aragonite suggesting dry cooling at relatively low temperature through the calcite field (Ghent et al., 1996). The tectonic blocks do not occur in contact with either serpentinite or within mélange, thus their mode of transport to the surface is not clear. The preservation of the high-pressure assemblage, including lawsonite and garnet with little or no retrogression suggest that the *P–T* transport to the surface took place relatively rapidly with little strong deformation and/or pervasive metamorphic fluids, e.g., Clarke et al. (2006). A possible relationship between the metamorphic history of the eclogite tectonic blocks and the blueschists is discussed later in this paper.

Ghent et al. (1993) estimated a minimum pressure of 12–13 kbar (1 kbar = 0.1 GPa) for the lawsonite-bearing eclogite based upon the absence of stable albite. Recently published geobarometers applicable

* Corresponding author. Tel.: +1 403 220 23 4540; fax: +1 403 284 0074.
E-mail address: ghent@ucalgary.ca (E. Ghent).

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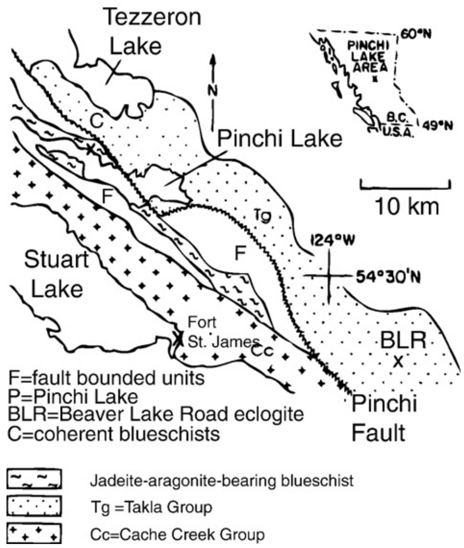

Fig. 1. Simplified geologic and index map showing location of Pinchi Lake area and locations of Beaver Lake eclogite (BLR).

to these rocks are available, allowing a reinvestigation of the *P*–*T* conditions of equilibration. In addition we now have improved X-ray mapping techniques and new software available (Tinkham and Ghent, 2005) that allow investigation of compositional variability within phases and calculation of effective rock compositions at the thin section scale. We have reinvestigated the Beaver Lake (BLR) tectonic block, choosing three samples showing little or no retrogression. In this paper we present new analytical data and estimates of pressure based upon garnet–clinopyroxene–phengite (Krogh Ravna and Terry, 2004) and talc–glaucophane–clinopyroxene equilibria (see, e.g., Massone and Kopp, 2005). We have also made new estimates of temperature based upon a more recent calibration of garnet–clinopyroxene Fe–Mg exchange equilibria by Krogh-Ravna (2000). Pressure–temperature phase diagram sections and observed garnet compositions are used to constrain the *P*–*T* conditions of garnet-core growth.

2. Petrography and mineral assemblages

The petrography and mineral assemblages of the Beaver Lake eclogite are described in Ghent et al. (1993). Briefly, lawsonite and omphacite occur as inclusions in garnet and also occur in the matrix (Fig. 2). Glaucophane occurs in the matrix but is rare or absent as inclusions in garnet. Phengite and talc occur in the matrix but not as inclusions in garnet. Quartz is present in small amounts in the matrix. Rutile is generally altered to titanite and a trace amount was detected in X-ray mapping. Obvious retrogression of garnet and omphacite is rare to absent.

3. Laboratory techniques

Electron microprobe analyses were performed on the JEOL-8200 instrument housed in the Department of Geology and Geophysics at the University of Calgary. Operating conditions for the mineral analyses were 15 kV accelerating voltage, 15–20 nA beam current and beam diameter 1–10 µm. Count times were 20 s on peak and 10 s on background. A list of mineral standards used is available from the senior author. Matrix corrections were made using the ZAF program supplied with the JEOL software. Element maps for Mg, Ca, Mn, and Fe were made on several garnets and these were used to pick the lines for the garnet traverses. For the quantitative element maps the procedures and the program XRMapAnal are described in Tinkham and Ghent (2005).

4. Mineral analyses

Mineral analyses reported in Ghent et al. (1993) were performed with an ARL SEMQ microprobe. We performed a large number of new analyses for this paper. We found very little differences in the compositions from those reported in the earlier study (Table 1 and Ghent et al., 1993).

We made eleven element maps for Ca, Fe, Mn, and Mg and some representative traverses are presented in Figs. 3 and 4. We used element maps as a guide to choose compositional traverse locations to ensure that the traverses passed through the compositional cores in the plane of the thin section. All garnet element maps and compositional traverses showed a Mn rich core with a decrease in Mn content toward the rim. This pattern was present in all maps and traverses, for a range in garnet crystal diameters from 700 to 3000 µm. This pattern has been typically interpreted as growth zoning (Tracy et al., 1976). Ca content shows little change from core to rim (Fig. 3). The Fe and Mg content shows very little change, but a plot of the Fe/Mg ratio for several garnets from three different samples shows a decrease from core to rim (Fig. 4). This feature has been interpreted by some workers to indicate increase in temperature during crystal growth.

The Na-amphibole crystals are typically color zoned with lighter cores and darker rims. Electron probe analyses confirmed that this represented an increase in Fe content, also see Ghent et al. (1993, Table 2, p.281).

Omphacite does not usually show color zoning and the jadeite (jd) content shows little or no increase from cores to rims. Omphacite inclusions are generally lower in jadeite content than omphacite in the matrix, but there is significant overlap in compositions. Inclusions usually contain 34–37 mol% jd with a range of 34–39 mol%. Matrix omphacite ranges from 34–44 mol% jd with most analyses in the range 37–42 mol% jd. Using recalculation with normalization to total cations = 4, the acmite content ranges from 13.5 to 18 mol%. With normalization to 2 cations with Si atoms = 2, the acmite content ranges from 13 to 15 mol%.

5. Estimates of pressure and temperature based upon mineral equilibria

5.1. Garnet–clinopyroxene Fe–Mg exchange equilibria

The garnet–clinopyroxene Fe–Mg exchange thermometer has been widely used as a geothermometer for eclogites, e.g., Ellis and Green (1979). The accuracy of this thermometer for clinopyroxene with significant Fe^{3+}/Fe^{2+} has been questioned (for a brief review see

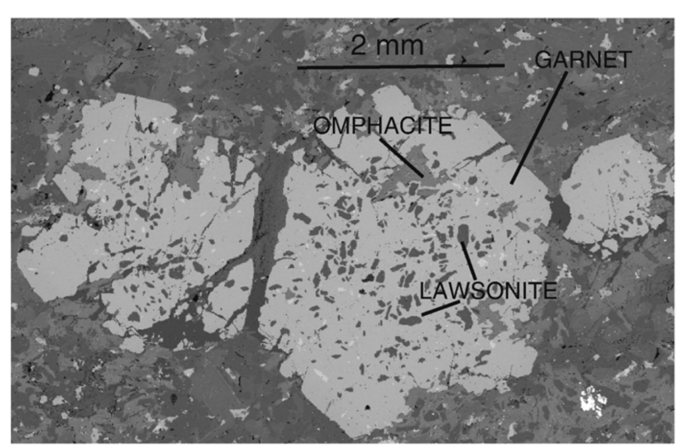

Fig. 2. Back-scattered electron map of sample BLR-3, showing garnet porphyroblasts with lawsonite, and omphacite inclusions. Talc adjacent to garnet.