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Zr-in-rutile thermometry in eclogite and vein from southwestern Tianshan, China

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ABSTRACT

Trace element LA–ICPMS analyses of rutile from eclogites and veins from southwestern Tianshan, China, are carried out for testing the validity of Zr-in-rutile thermometry in low-T/UHP eclogites. Mineral inclusions in rutile and time-resolved mass spectrometer data are carefully examined to identify and reject contaminated data. The Zr contents vary between individual grains from the same sample; rutile inclusions in garnet, amphibole, and paragonite have a narrower range of Zr contents than matrix rutiles that always show the highest Zr contents, which reflects the progressive rutile growth in the eclogites. Average Zr concentrations in rutile from all six investigated eclogite samples statistically belong to one well-defined population (34 ± 5 ppm; 33 ± 11 ppm; 26 ± 7 ppm; 36 ± 17 ppm; 22 ± 6 ppm; 40 ± 17 ppm), while average Zr concentration in rutile from the three veins belong to a second well-defined population (55 ± 7 ppm; 66 ± 6 ppm; 55 ± 5 ppm). The peak temperature of eclogite can be estimated as 535–570 °C at a pressure of 2.7 GPa inverted from the discovery of well preserved coesite in an increasing number of rocks from southwestern Tianshan. The mineral assemblage of the veins suggests their retrograde formation in the epidote–amphibolite facies; the growth temperature of vein rutile is 530–540 °C at ~1.0 GPa. A robust P–T path constructed by Zr-in-rutile thermometry in eclogites and veins indicates that the rocks underwent a rapid uplift involving an early isothermal decompression from eclogite to epidote–amphibolite facies. Zr in rutile from eclogites and veins can serve as a pressure indicator in study area that suggests the pressure has a significant effect to the Zr-in-rutile thermometry.

1. Introduction

Zr-in-rutile thermometry is a recently developed method for estimating metamorphic temperatures based on the Zr content of rutile coexisting with quartz and zircon (Zack et al., 2004; Watson et al., 2006; Ferry and Watson, 2007; Tomkins et al., 2007). Due to its simplicity and practicality, Zr-in-rutile thermometry has been applied to different geologic settings and a wide variety of rock types, including extreme geologic environments from ultrahigh-temperature (UHT) granulites (e.g. Baldwin and Brown, 2008; Luvizotto and Zack, 2009; Jiao et al., 2011; Meyer et al., 2011) to ultrahigh-pressure eclogites (e.g. Zack and Luvizotto, 2006; Chen et al., 2007, 2009; Chen and Li, 2008; Gao et al., 2010; Vaggelli et al., 2008; Zhang et al., 2009, 2010; Zheng et al., 2011) and low-temperature blueschists (Spear et al., 2006). Previous studies showed that temperatures calculated by the Zr-in-rutile thermometer may reflect progressive growth (Spear et al., 2006; Zhang et al., 2010; Zheng et al., 2011), peak metamorphism (Zack and Luvizotto, 2006; Miller et al., 2007; Zhang et al., 2010), or retrograde equilibration (Chen and Li, 2008; Zhang et al., 2010). Therefore, the method could reveal different stages of subduction-zone metamorphism.

The blueschist–eclogite belt in southwestern Tianshan, China, is a typical LT/HP–UHP oceanic subduction zone (Zhang et al., 2008a), with the characteristic occurrence of various HP veins in metabasites (Beinlich et al., 2010; Gao and Klemd, 2001; Gao et al., 2007; John et al., 2008; van der Straaten et al., 2008; Lü et al., 2012). Rutile is a common constituent in eclogitic rocks and veins crosscutting them. Both conventional geothermobarometry and quantitative phase diagrams have been used to determine the peak P–T conditions of eclogitic rocks from southwestern Tianshan; there is, however, a distinct difference among P–T estimates of different samples (e.g. Gao et al., 1999; Beinlich et al., 2010; John et al., 2008; Klemd et al., 2002, 2011; Wei et al., 2003, 2009; Lü et al., 2007, 2008, 2009, 2012). This study focuses on the application of Zr-in-rutile thermometry to eclogites and veins from southwestern Tianshan, China. The results answer the following questions: (1) Did the eclogites form at similar metamorphic P–T conditions? (2) Which evolutionary stage does the rutile thermometry in the veins reflect? (3) Which metamorphic P–T path could be reconstructed from rutile of eclogites and veins?

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2. Geological setting and sample description

The blueschist–eclogite belt of southwestern Tianshan is located between the Yili–Central Tianshan and Tarim plates along the South Central Tianshan suture, mainly in Zhaosu county of Xinjiang province, China (Fig. 1). It is bounded by two ductile shear zones; the northern separates it from a low pressure/high temperature metamorphic belt consisting of cordierite-bearing garnet–sillimanite gneiss and two-pyroxene granulite (Li and Zhang, 2004), and the southern from a unit of interlayered marble and chlorite–white mica schist (Zhang et al., 2008a). The blueschist–eclogite belt consists of eclogite, blueschist, phengite schist and greenschist associated with serpentinized ultramafic rocks (Gao et al., 1999; Klemd et al., 2002; Zhang et al., 2007). Eclogite and blueschist mainly occur as lenses and blocks in prevalent garnet–mica schists. Geochemical studies suggest oceanic affinity of the protoliths of these HP–UHP metabasic rocks (Gao and Klemd, 2003; Ai et al., 2006). Veins are ubiquitous and form networks in eclogites and bluschists of centimeter to meter scale. They are predominantly composed of omphacite, quartz, epidote, amphibole, carbonate, garnet and rutile in variable modal proportions (Gao and Klemd, 2001; Gao et al., 2007; Lü et al., 2012).

Well preserved coesite inclusions were recently discovered in eclogitic rocks from the Habutengsu–Kebuerte unit (HKU, Fig. 1; Lü et al., 2008, 2009, 2012; Lü and Zhang, 2012; Yang and Zhang, 2010) and undoubtedly proved that most schists and eclogites in this region underwent UHP metamorphism (Zhang et al., 2002a,b, 2003, 2005). Lawsonite recently found in chloritoid–glaucophane schists and eclogites in HKU (Du et al., 2011) furthermore emphasizes that the bluschist–eclogite belt in southwestern Tianshan is a typical cold oceanic subduction zone. Published peak P–T estimates vary strongly from 400–600 °C at 1.7–3.2 GPa; they are mainly based on conventional geothermobarometry and quantitative phase diagrams applied by researchers to rocks from several outcrops (e.g. Gao et al., 1999; Beinlich et al., 2010; John et al., 2008; Klemd et al., 2002, 2011; Wei et al., 2003, 2009; Lü et al., 2007, 2008, 2009, 2012).

The studied suite comprises nine samples (six eclogites, three veins) from an internally coherent terrain (i.e., HKU) of southwestern Tianshan (Fig. 1; Table 1). The eclogites consist of garnet + omphacite + white mica + quartz + amphibole + epidote + rutile + titanite + apatite ± carbonate. Three vein samples were picked from the same valley in Habutengsu area as eclogites H0906 and H0907. Like the veins reported by Lü et al. (2012), the boundaries between the veins investigated here and their host rocks are sharp and neither alteration selvages nor transition zones were identified. These veins are intimately associated with coesite-bearing eclogitic rocks (Lü et al., 2008, 2009, 2012; Lü and Zhang, 2012), and have variable sizes of thin section to hand specimen scale. The mineral assemblage of the veins is quartz + epidote ± amphibole + white mica + carbonate + chlorite + rutile + titanite ± apatite; they lack garnet and omphacite. Based on their major constituents, these three veins can be sorted into two groups: (1) quartz - carbonate vein (samples H711 and H10-6), and (2) epidote - amphibole vein (sample H10-3A).

3. Analytical methods

Thin sections were polished to about 100 μm thickness in order to facilitate the analysis by electron probe and laser ablation ICPMS. Petrographic investigation focused particularly on the textural occurrence of rutile and its inclusions and was performed on a JEOL JXA-8230 electron probe in the Key laboratory of metallogeny and mineral assessment of MLR, Institute of Mineral Resources, China. Mineral chemistry was quantitatively analyzed at 15 kV acceleration voltage and 2×10^{-8} A beam current; ZAF correction was applied. Mineral inclusions in rutile, too small for quantitative analyzes, were only qualitatively checked with an energy dispersive spectrometer (EDS) on the same machine.

Trace elements in rutile were analyzed by LA–ICPMS at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan. Laser sampling was performed using a GeoLas 2005. An Agilent 7500a ICP-MS instrument was used to acquire ion-signal intensities. Ablation spot size was set to 24 μm, with the laser energy of 65 mJ and a frequency of 6 Hz. Each analysis incorporated a background acquisition of approximately 20–30 s (gas blank) followed by 50 s data acquisition from the sample. Element contents were calibrated against multiple-reference materials (BCR-2G, BIR-1G and BHVO-

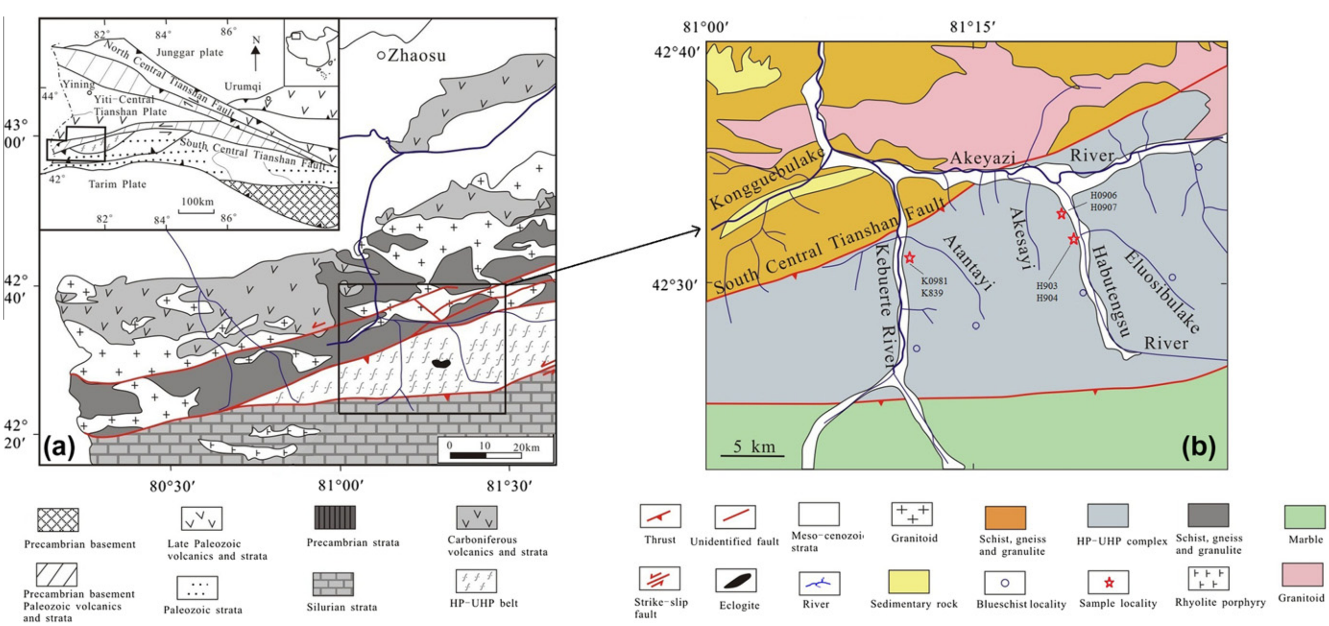

Fig. 1. (a) Simplified geological map of southwestern Tianshan orogen and (b) sampling localities of the HKU eclogites and veins (after Lü et al. (2012)). HKU denotes the Habutengsu–Kebuerte unit in the LT/UHP eclogite facies. The vein samples were picked from the same valley in Habutengsu area where well preserved coesite in eclogite was first discovered by Lü et al. (2009).