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Zircon U–Pb ages and Hf isotopic analyses of migmatite from the 'paired metamorphic belt' in Chinese SW Tianshan: Constraints on partial melting associated with orogeny

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ABSTRACT

A paired metamorphic belt with ubiquitous migmatites and rare granulites in its high dT/dP part formed due to oceanic subduction in Chinese southwestern (SW) Tianshan. Although several geochronological studies have addressed it in recent years, the exact timing of the high-grade metamorphism and partial melting is still controversial. For this study, we selected nine samples obtained from three valleys transecting the SW Tianshan Migmatite Complex for U–Pb geochronology and Lu–Hf isotope analysis to provide constraints on partial melting and the mid-crustal evolution during oceanic subduction and subsequent continental collision.

On the basis of internal morphology, Th/U ratios and REE patterns, three types of zircons are discriminated. Dating them reveals five age groups: (1) Inherited zircons either are detrital, with ages scattering from 432 Ma to 3261 Ma, or yield ages concentrated at 406–410 Ma reflecting Early Devonian magmatism; (2) Recrystallized zircon has been transformed from pre-existing zircon under subsolidus conditions at ~400 Ma and ~360 Ma; (3) Metamorphic rims have grown on zircons at ~400 Ma, ~290 Ma and ~270 Ma, corresponding to three phases of anatexis. The partial melting phase at ~400 Ma is probably related to the emplacement of voluminous mafic to felsic magmas in a continental arc region above the subduction zone consuming the South Tianshan Paleo-Ocean that triggered the most extensive regional-scale thermal event. However, the two subsequent partial melting phases at ~290 Ma and ~270 Ma representing post-collisional stages were not penetrative. P–T conditions of the studied migmatites estimated by Hb–Pl thermobarometry and Ti-in-zircon thermometry are 682–763 °C, 4.7–8.0 kbar; together with composite Kfs + Q + Pl, Kfs + Q and Kfs + Q + Ab inclusions representing entrapped melt and Kfs inclusions with Ab exsolution lamellae in zircon rims, the P–T estimates support the occurrence of anatexis. Zircon Lu–Hf isotope analysis indicates that zircon rims formed under high-grade metamorphic conditions and during partial melting by dissolution–precipitation of pre-existing zircons in a close system. Zircon two-stage Hf model ages constrain the development of the protoliths of the migmatites at four major crustal formation periods (~1871 Ma, 1368–1426 Ma, 1099–1276 Ma and 743 Ma). Combined with previous researches in this area, we conclude that the main crustal formation of the Yili and Central Tianshan Plates has mostly occurred in Proterozoic times, but not or only subordinately during the Archean.

1. Introduction

Migmatite complexes pervasive in orogenic belts worldwide provide an excellent opportunity to study the crust's behavior during orogenies and thus they have received much attention from geoscientists in recent years (Brown, 2001; Foster et al., 2001; Keay et al., 2001; Rubatto et al., 2009; Vavra et al., 1999; White, 2008; Wu et al., 2007a). The dating of migmatites helps to understand the relationship between partial melting and the associated orogenic processes (Foster et al., 2001; Keay et al., 2001; Rubatto et al., 2009; Whitney et al., 2003), however, in many orogens it is difficult to constrain the timing of partial melting, because of multi-stage metamorphism, repeated fluid influx, or limited existence of decent outcrops (Foster et al., 2001; Keay et al., 2001; Rubatto et al., 2009).

Zircon is of particular importance for the investigation of migmatite complexes, because its properties make it a unique recorder of the thermal history its host rocks have experienced (Flowerdew et al., 2006). Due to its refractory nature and the low Pb diffusivity below temperatures of ca. 900 °C (Lee Dagger et al., 1997), zircon can retain at least parts of its radiometric memory during high-grade metamorphism and partial melting (Vavra et al., 1996, 1999). With in-situ high-resolution techniques, zircon can be dated to unravel detailed chronological information on different periods of metamorphism and partial melting, and even on the protolith formation (Flowerdew et al., 2006; Foster et al., 2001; Vavra et al., 1999). However, zircon's inertness and resistance

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could also be a mixed blessing: On the one hand, its refractory nature and the high closure temperature of the U–Pb diffusion only lead to partial disturbance of the isotopic system through thermal events and, thus, a wealth of age information on successive geological processes might be accumulated in it (Flowerdew et al., 2006; Vavra et al., 1996, 1999; Wu et al., 2007a). On the other hand, zircon can be structurally and morphologically complex, which makes acquisition and interpretation of the radiometric data difficult (Vavra et al., 1996, 1999; Wu et al., 2007a). To master these problems, detailed analysis of zircon's morphology and internal structure should be conducted by CL (cathodoluminescence) imaging prior to dating. Zircon's Th–U and REE contents can provide constraints on mechanisms related to its formation. Moreover, the Lu–Hf isotope system refractory in zircon during partial melting can be used to unravel melt generation, the mechanisms leading to formation of complexly zoned zircon during anatexis and the nature of the protolith (Flowerdew et al., 2006; Lin et al., 2012; Liu et al., 2010a; Wu et al., 2007a,b).

The Chinese SW Tianshan Migmatite Complex was traditionally associated with Early Precambrian basement, the "Nalati Group" (BGMRXUAR, 1993; Gao et al., 1995; Wang et al., 2010), but according to recent studies it is the high dT/dP part of a "paired metamorphic belt" formed by subduction of the South Tianshan Paleo-Ocean underneath the Yili Plate (Li and Zhang, 2004; Zhang et al., 2007). Although geochronological studies have addressed the Migmatite Complex in recent years (Gou, 2012; Li and Zhang, 2004), the exact timing of the anatexis is still not well constrained, because investigated samples were taken in small areas only and do not reflect the complicated thermal evolution of the whole region sufficiently and the complex internal zircon structure was not clearly attributed to distinct thermal events.

In this paper, we systematically analyze zircons from nine samples taken in three valleys transecting the SW Tianshan Migmatite Complex and obtain CL images, U–Pb ages, Th–U and REE contents, and Hf isotopic data to elaborate different stages of regional thermal events and the relationship between partial melting and orogenic processes. Mineral abbreviations follow Whitney and Evans (2010).

2. Geological background

The Tianshan Orogen is situated on the southern margin of the Central Asian Orogenic Belt (CAOB) and extends for ~2500 km in China and its neighboring countries Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan, from east to west (Fig. 1a). Located at its southern margin in the Xinjiang province, NW China, Chinese SW Tianshan marks the boundary between the Tarim and Yili Plates, which collided in Late

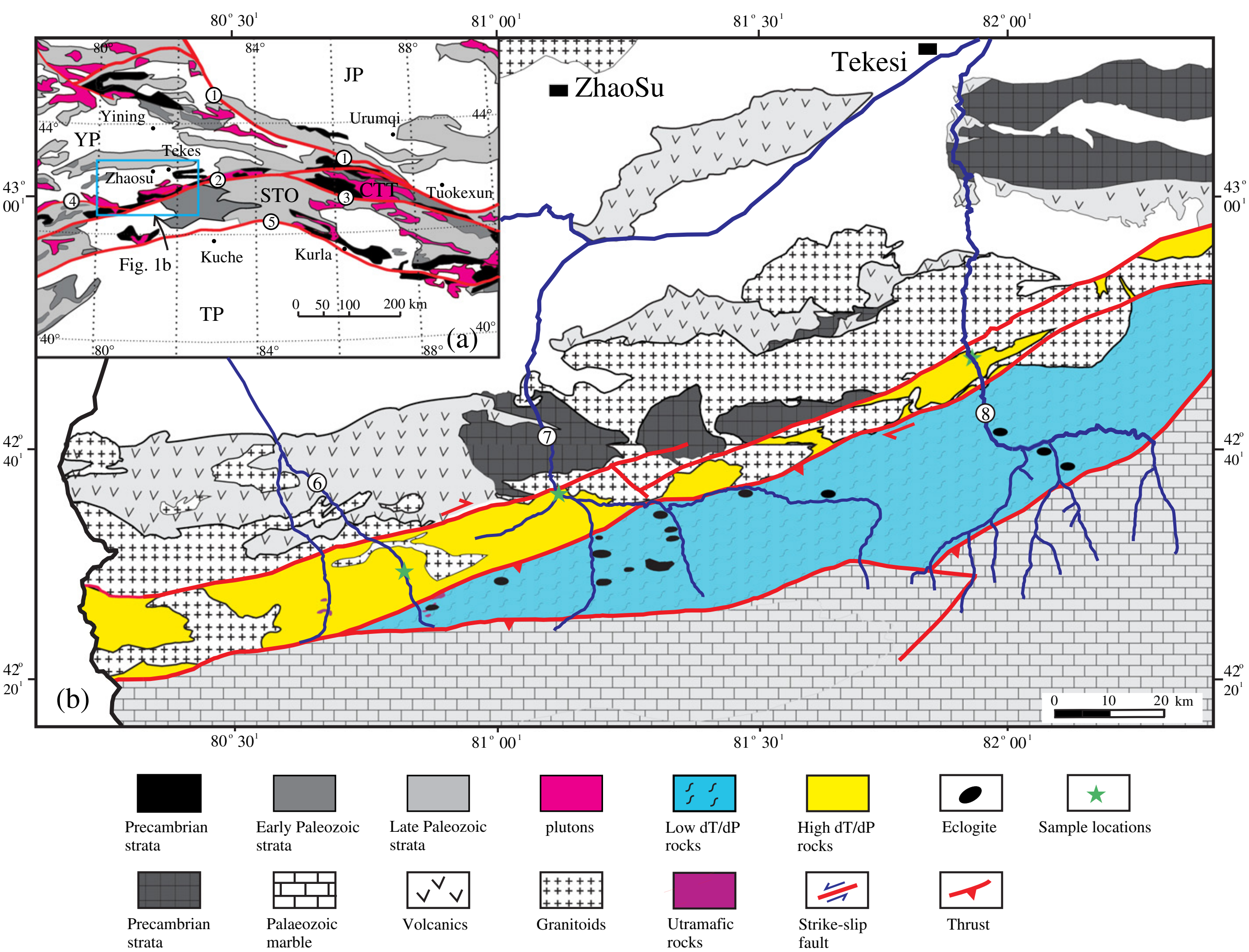

Fig. 1. (a) Tectonic framework of the Tianshan Orogenic Belt (modified from Gao et al., 2009; Wang et al., 2010) located at the southern margin of the CAOB and reflecting the Late Paleozoic collision of several blocks between the Tarim and Siberia Cratons. (b) Simplified geological map of the Chinese southwestern Tianshan Orogenic Belt (modified from Lü et al., 2012). A paired metamorphic belt (blue and yellow color) formed due to northward subduction of the South Tianshan Paleo-Ocean under the Yili Plate comprises a low dT/dP blueschist–eclogite belt in the south and a high dT/dP granulite–migmatite belt in the north,. 1 North Tianshan Fault, 2 Qingbulak–Nalati Fault, 3 Baluntai Fault, 4 Nikolaev Line, 5 North Tarim Fault, 6 Muzhaerte Valley, 7 Akeyazi Valley, 8 Kekesu Valley; YP Yili Plate, JP Junggar Plate, TP Tarim Plate, CTT Central Tianshan Terrane, STO South Tianshan Orogen.