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Decompressional anatexis in the migmatite core complex of northern Dabie orogen, eastern China: Petrological evidence and Ti-in-quartz thermobarometry

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ABSTRACT

The voluminous diatexites in the Dabie orogen of eastern China indicate spectacular anatexis in the orogen basement before exhumation to shallow depths, but determination of the pressure–temperature (P–T) conditions for anatexis in the core complex is problematic because of the lack of suitable mineral assemblages in the diatexite and of re-equilibrations during the retrograde stages. To overcome this problem, we studied an amphibolitic migmatite, which occurs as a raft in the diatexites of the central dome and has been partially melted at a very low degree. In such rocks with low degree of melting, the microstructures still reveal the high temperature melting reactions, and thus mineral analyses can be used to constrain anatectic P–T conditions and interpret the geochemical characteristics of partial melts. We demonstrate from petrological evidences that incongruent partial melting of amphibole + plagioclase + quartz lead to the formation of clinopyroxene and silicate melt. Trace element analyses of clinopyroxenes confirm that they have been equilibrated with anatectic melts. Two types of amphiboles can be identified, and the amphibole cores have high Al_2O_3 (>9.0 wt.%) and TiO_2 (>1.5 wt.%) contents suggesting a nearly constant temperature of 850–850 °C with a pressure varying from 6 to 2 kbar. In contrast, the rims of some amphibole grains have low Al_2O_3 (<8.0 wt.%) and TiO_2 (<1.2 wt.%) contents indicating temperatures lower than 750 °C at low pressures (<2 kbar). We propose two distinct phases in the tectonic evolution of the migmatite core complex in the northern Dabie orogen. The early-stage is a near-isothermal exhumation and the investigated rocks are characterized by a decompression from more than 20 km to ~6 km. Low degree partial melting in the infertile quartz-poor amphibolite occurs at low pressure during this exhumation phase. The second phase is characterized by a shallow (nearly isobaric) cooling stage.
These two tectonic phases are recorded in quartz grains using Ti-in-quartz thermobarometry. The quartz in contact with or enclosed in clinopyroxene and plagioclase is characterized by Ti concentrations with an average value of ~50 ppm. These quartz grains have been equilibrated at high temperatures and pressures during the anatexis and were chemically isolated in Ti-poor phases during the low-pressure cooling phase. On the other hand, the quartz enclosed in amphibole has much higher Ti concentrations up to ~140 ppm which is the result of further incorporation of Ti released from the host mineral during the low pressure cooling. Diffusion modeling on one Ti concentration profile in quartz enclosed in amphibole suggests fast cooling within 800–650 °C with a rate of ca. 0.2 °C/yr. This study demonstrates that the application of the Ti-in-quartz thermobarometer to lithologies with low fertility may be extremely helpful to constrain anatectic P–T conditions and exhumation history of migmatized orogen basements.

1. Introduction

Continental orogens generally evolve along a route well known as the Wilson Cycle, which ends with intense thinning of orogens occurring by means of exhumation. Deep partial melting (anatexis) in the continental crust has a critical effect on weakening rocks and promoting deformation (Jamieson et al., 2011; Rosenberg and Handy, 2005), which finally cause architectural rebuilding, chemical differentiation and rapid exhumation of thick mountain belts (Rey et al., 2001). Such an anatexis-induced crustal evolution scenario may have been in progress for the active Himalaya (Ganguly et al., 2000; Harris and Massey, 1994; Harris et al., 2004) and may have played an important role in the exhumation processes of numerous ancient continental

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collision orogens, such as the Variscan orogen of central Europe (Brown and Dallmeyer, 1996) and the Appalachian orogen of North America (Solar and Brown, 2001). To dissect the mechanisms controlling orogen exhumation, structural evidence and thermodynamic modeling have merits for decoding the deformation and metamorphic paths (Schulmann et al., 2008; White et al., 2005), while petrological microstructures are of particular importance in recognizing anatexis (Holness et al., 2011).

The exhumation history of the Dabie orogen, namely the pressure–temperature-time (P–T–t) path, has been widely investigated by phase equilibrium thermodynamics for the P–T paths (e.g. Cong et al., 1995; Wei et al., 1998; Zhang et al., 2009) and by isotopic thermochronologies for the T–t paths (e.g. Eide et al., 1994; Hacker et al., 2000; Li et al., 2000; Liu et al., 2010; Ratschbacher et al., 2000). These investigations, which have been mainly performed on ultra high-pressure (UHP) and high-pressure (HP) metamorphic rocks or their debris in sediment basins, revealed multiple cooling/exhumation stages with different cooling rates for UHP-HP rocks [see views of Li et al. (2005), Wang et al. (2008) and Wu and Zheng (2013)]. Recently, partial melting of the UHP-HP rocks during exhumation at great depths (>20 kbar) in the Dabie-Sulu orogenic belt has been evidenced by geochemical and petrological studies (Chen et al., 2013; Wang et al., 2013; Xu et al., 2013; Zhao et al., 2012) and confirmed by high-pressure melting experiments (Liu and Wu, 2013).

However, a late lithospheric extensional and orogenic doming at the Cretaceous (Wang et al., 1998, 2011), which might finally brought the UHP-HP rocks to the near-surface level (Faure et al., 1999; Hacker et al., 1995), was poorly constrained for the P–T–t path and the relevant information can hardly be derived from studies on eclogite-facies rocks. Thermochronological studies on a large body of basement samples collected across the Dabie orogen provide important data on the final-stage low-temperature (<400 °C) exhumation processes (e.g. Grimmer et al., 2003; Reiners et al., 2003), which however cannot constrain the high-temperature (>600 °C) migmatization-related crustal extensional processes in the core complex. It is also notable that many thermochronological approaches usually need to transfer isotopic closure temperatures to pressures by assuming P/T gradients and this approach may result in great uncertainties without well-constrained thermal-depth profile for a geological period (England and Molnar, 1990), because P/T gradients usually vary widely along the evolution path of an orogenic belt (England and Thompson, 1984; Thompson et al., 1987).

Compared to studies on eclogites and low-temperature thermochronologies, thermodynamic researches on granulites from the migmatite core complex of the northern Dabie orogen (Chen et al., 1998, 2006) may provide information more closely associated with the P–T path of doming processes, and the results show that temperatures as high as 850–900 °C could have been reached during the last exhumation stage at pressures below 6 kbar. Such a high temperature would induce extensive anatexis in the basement rocks of the dome, as being proved by zircon dating for felsic migmatites (Wu et al., 2007), which in turn would promote further crustal extension and exhumation (Faure et al., 1999). However, granulites tend to be sluggish at lower P–T conditions after peak metamorphism, especially when they have been previously depleted in felsic components in earlier anatectic events. Therefore, although some P–T–t information about exhumation of the migmatite core complex of the northern Dabie orogen has been obtained from investigations on granulites, further studies are required to improve our understanding of the coupling between anatexis and exhumation during the Cretaceous crustal extension of the Dabie orogen. For this purpose, we present a mineralogical and geochemical study on an amphibolitic metatexite which is enclosed in diatexites of the central dome of the Northern Dabie. This rock type suffered low-degree partial melting along a decompressional path, and the results are used to contain the P–T conditions associated with low pressure anatexis and exhumation.

2. Geological background

The Dabie orogen is a part of the Qinling-Tongbai-Dabie-Sulu UHP-HP metamorphic terrane in eastern China. The exhumation of the UHP rocks from >100 km depth to the upper crust was accomplished by multiple stages (Li et al., 2005; Wu and Zheng, 2013), while the last exhumation stage at the Early Cretaceous has been suggested to be dominated by crustal extension and doming (Hacker et al., 1995; Ratschbacher et al., 2000). Furthermore, the Early Cretaceous tectonic extension has effected a large scale area of eastern China (Wu et al., 2005), the driving force has been ascribed to upwelling of hot asthenospheric mantle (Huang et al., 2007; Jahn et al., 1999; Wang et al., 2007; Xie et al., 2011; Zhao et al., 2005) and/or associated with the northwestward subduction of the Paleo-Pacific Plate beneath East China (Li and Li, 2007; Zhang et al., 2011).

Based on metamorphic grades, the Dabie orogen can be divided into several petrotectonic units outlined by faults (Fig. 1) (You et al., 1996; Zhang et al., 1996), which are the Northern Dabie high-temperature metamorphic core complex, the Central Dabie medium-temperature UHP-HP metamorphic rocks, and the Southern Dabie low-temperature ultra high-pressure metamorphic rocks, and the Su-Song Unit (SSU) of low-temperature UHP-HP metamorphic rocks. The core complex dome in the Northern Dabie is characterized by extensive and intensive migmatization (Faure et al., 1999) and is composed of an outer metatexite zone and an inner diatexite zone (Fig. 1). Zircon U–Pb dating of leucosomes of grey diatexite (Wu et al., 2007) indicates that anatexis of the orogenic basement occurred nearly simultaneously with the large-scale post-collisional granitoid plutonism at 145–120 Ma (Ma et al., 1998; Xu et al., 2007; Zhang et al., 2010). The voluminous Early Cretaceous granitoids in the Dabie orogen can be divided into two types based on distinct ages and geochemical features (He et al., 2011; Wang et al., 2007; Xu et al., 2007), including (1) the early-stage (145–130 Ma) granitoids derived from orogenic root of the thickened

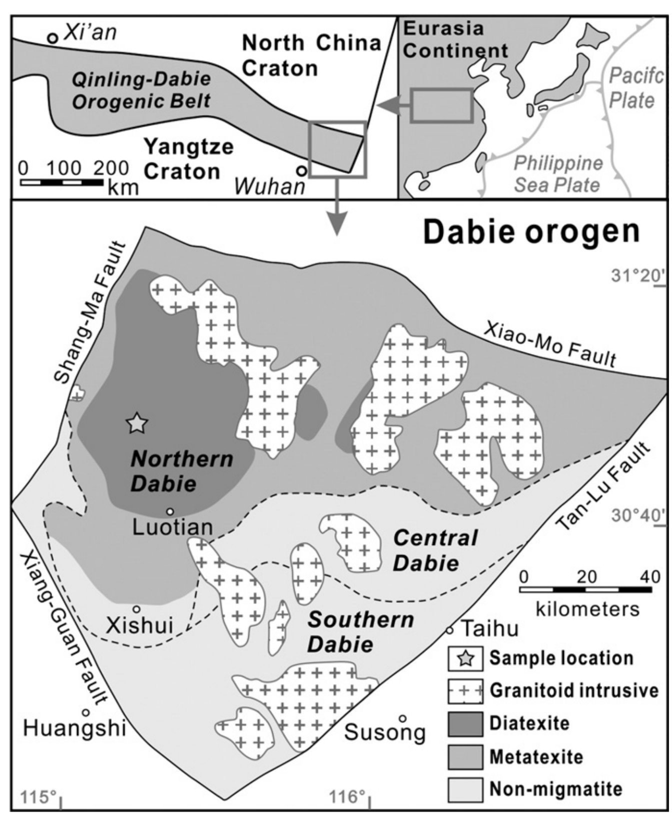

Fig. 1. Geological sketch map of the Dabie orogen (modified after Faure et al., 1999). The sample location is within the diatexite zone, near the center of the migmatite dome in the Northern Dabie.