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Protolith control on fluid availability for zircon growth during continental subduction-zone metamorphism in the Dabie orogen

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ABSTRACT

Different episodes of zircon growth are recognized by a combined study of CL images, mineral inclusions, U–Pb ages, trace elements and Lu–Hf isotopes for ultrahigh-pressure (UHP) eclogite-facies metamorphic rocks in the Dabie orogen. The results provide insights into the effect of protolith property on fluid liberation during continental collision. Fluid availability from premetamorphic protoliths of different origins is recognized as a key to the zircon growth. Zircon U–Pb dating for UHP metabasalt and metasediment (eclogite and its host paragneiss) yields two groups of ages at 244 ± 3 and 225 ± 2 Ma, respectively. Mineral inclusion, trace element and Lu–Hf isotope analyses also suggest that these two groups of zircon grew from hydrous melt during the final subduction and supercritical fluid during the initial exhumation, respectively. In contrast, zircon U–Pb dating for UHP metaintrusive rocks (granitic orthogneiss and its hosted eclogite) gave only one group of age at 222 ± 2 Ma. Mineral inclusion, trace element and Lu–Hf isotope analyses suggest that the metamorphic zircon grew from aqueous fluid during the initial exhumation. The difference between the two groups of zircon U–Pb dates is attributed to the difference in their protolith origin. Volcanic and sedimentary rocks contain large amounts of water primarily in the form of molecular water (pore fluid), so that considerable amounts of aqueous fluid can be released from them during subduction. This episode of fluid action was recorded by the growth of anatectic zircon at ~244 Ma. In contrast, intrusive rock only contains small amounts of water primarily in the form of structural hydroxyl in crystalline minerals, so that little fluid can be released from them during subduction. Nevertheless, large amounts of retrograde fluid were released from UHP metamorphic rocks regardless of their protolith origin during decompression exhumation. This episode of fluid action was recorded by the growth of metamorphic and anatectic zircons at 220–225 Ma. Therefore, the protolith property is a key to the liberation of aqueous fluid from metamorphosing rocks during subduction, which has great bearing on partial melting, element transport and mineral growth during continental subduction-zone metamorphism.

1. Introduction

Availability of aqueous fluid inside metamorphosing slices is a key to mass transfer and mineral growth during subduction-zone metamorphism (e.g., Rumble et al., 2003; Zheng et al., 2003a; Bebout, 2007). However, it is still uncertain which factor dictates the fluid availability during continental subduction-zone metamorphism. Protolith lithology may be a factor because different protolith types, either intrusive, volcanic or sedimentary rocks, contain different amounts of aqueous fluid. The structural hydroxyl and molecular water are two common hydrous species in ultrahigh-pressure (UHP) metamorphic minerals, and their dissolution into and exsolution from the minerals with changes in P–T conditions during subduction and exhumation have great bearing on the fluid availability (Zheng, 2009). In particular, the pore fluid (molecular water) is very susceptible to transport with the P–T changes during metamorphism, whose presence or absence may dictate the fluid availability during high-pressure (HP) to UHP metamorphism in subduction channels (Zheng, 2012).

The continental crust may act as both a source and a sink for aqueous fluid during subduction, which contrasts the subducting oceanic crust with the fluid budget (Zheng, 2009, 2012). The upper continental crust is primarily composed of granitic-granodioritic magmatic rocks (Taylor and McLennan, 1995), whereas the lower crust is generally composed of granulite-facies metamorphic rocks (Rudnick and Fountain, 1995). The both magmatic and metamorphic rocks serve as crystalline basement for sedimentary covers. Likewise, the oceanic crust is primarily composed of basaltic-gabbroic magmatic rocks with sedimentary covers. Despite their structural similarity, water contents in the continental crust are considerably lower than those in the oceanic crust because of the

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significant difference in pore water abundance between continental and oceanic supracrustal rocks. The oceanic supracrustal rocks are primarily composed of altered oceanic basalt and sediment, which contain large amounts of pore water. In contrast, the continental supracrustal rocks are generally composed of not only sedimentary and volcano-sedimentary rocks but also intrusive and volcanic rocks, which contain small amounts of pore water (Zheng, 2009, 2012). This difference has been regarded as a key factor in dictating the presence or absence of arc magmatism above the different types of subduction zone (e.g., Liou et al., 1997; Zheng et al., 2003a). Although the water release from subducting continental supracrustal rocks is not sufficient to cause the arc magmatism, it may have great bearing on mass transport and mineral growth during continental subduction-zone metamorphism.

Zircon is a robust phase in most geological environments and thus is perfect for geochronological dating and geochemical tracing. The zircon growth is very critical to its availability for microbeam in-situ U–Pb dating and geochemical analyses, and fluid availability has been a key factor in dictating the zircon growth during metamorphism (Zheng, 2009). The solubility of Zr in metamorphic fluid/melt is an important issue in dealing with the metamorphic growth of zircon. Because both aqueous fluid and hydrous felsic melt have very low Zr solubility, zircon is susceptible to saturation in the metamorphic fluid/melt (Zheng, 2009; Xia et al., 2010). As a result, new zircon growth starts as soon as the Zr saturation is achieved in the fluid/melt. The decrease of Zr solubility can be achieved by reducing temperature (e.g., Roberts and Finger, 1997), changing the fluid/melt composition either by addition of elements like Si and Al or by extraction of elements like Na and K as a result of mineral crystallization (Tichomirowa et al., 2005).

A great number of studies have demonstrated that different origins of zircon occur in UHP metamorphic rocks in the Dabie–Sulu orogenic belt (e.g., Zheng et al., 2004, 2005a, 2007a; Zhao et al., 2006; Chen et al., 2007, 2010, 2011, 2012, 2013; Liu et al., 2004a, 2004b, 2006a, 2006b, 2008, 2012; Xia et al., 2009, 2010; Zheng, 2009; Liu and Liou, 2011; Sheng et al., 2012). An important progress in these studies is zirconology: the use of element and isotope signatures in zircon grains, along with trapped mineral inclusions in this accessory phase. As a consequence, zircon is not only a valuable geochronometer to evaluate the timing of fluid action, but also a geohygrometer to detect the presence or absence of aqueous fluid and hydrous melt during subduction and exhumation of the continental crust (Zheng, 2009, 2012; Chen et al., 2013; Li et al., 2013). In particular, zircon trace element, U–Pb, Lu–Hf and O isotope systems can be reset to variable degrees, depending on the volume, composition, temperature and accessibility of aqueous fluid and hydrous melt.

In this study, we select two different occurrences of eclogites and their host gneisses from the Dabie orogen in order to evaluate the effect of fluid availability on zircon growth during subduction and exhumation. In-situ microbeam analyses of zircon U–Pb ages, Lu–Hf isotopes and trace elements were performed to distinguish different ages of metamorphic zircon, and then to trace the fluid origin in different protolith lithologies. The results indicate that the presence or absence of aqueous fluid and hydrous melt during continental subduction-zone metamorphism dictates the growth of metamorphic zircon and the recrystallization of protolith zircon. This provides insights into the effect of protolith property on zircon growth during continental subduction-zone metamorphism.

2. Geological settings and samples

UHP metamorphic rocks widely occur in the Dabie–Sulu orogenic belt, representing exhumed products of the deeply subducted continental crust (Zheng, 2008). It has been well established that subduction of the South China Block beneath the North China Block took place in the Triassic (Zheng et al., 2009; Liu and Liou, 2011). This orogenic belt is separated into eastern and western sections by the Tanlu Fault, respectively, which are named as the Sulu and Dabie orogens (Fig. 1). The Dabie orogen extends across Anhui and Hubei provinces in the west and is in fault contact with the Hong'an orogen (Wu and Zheng, 2013). It consists of a series of fault-bounded metamorphic units that can be subdivided into five main tectonic zones from north to south (Zheng et al., 2005b): (1) the Beihuaiyang low-T/low-P greenschist-facies zone, (2) the North Dabie high-T/UHP granulite-facies zone, (3) the Central Dabie medium-T/UHP eclogite-facies zone, (4) the South Dabie low-T/UHP eclogite-facies zone, and (5) the Susong low-T/high-P blueschist-facies zone. Nevertheless, there is still controversy about the property of lithotectonic unit in North Dabie, particularly about the occurrence of diamond and eclogite (Zhang et al., 2009a; Liu and Liou, 2011).

According to field occurrence and country-rock associations, three types of eclogites are recognized in the Dabie orogen (Cong, 1996; Fu et al., 1999; Zheng et al., 2003b, 2012): (1) G-type, principally as enclaves or layers within the granitic orthogneiss of intrusive protolith, only few interlayered with the biotite paragneiss of volcanic and sedimentary protoliths; (2) M-type, interlayered with or as enclaves within marble or calc-silicate rocks; and (3) P-type, either members of layered mafic–ultramafic intrusions or simply in association with ultramafic rocks (peridotite or pyroxenite). The present study focuses on G-type eclogites and their host gneisses at two localities (Bixiling and Shuanghe) in the Central Dabie medium-T/UHP eclogite-facies zone (Fig. 1).

Many geochronological studies have devoted to eclogites and eclogite-facies rocks at Bixiling and Shuanghe, including mineral Sm–Nd isochron dating (Chavagnac and Jahn, 1996; Li et al., 2000; Jahn et al., 2003) and zircon U–Pb dating (e.g., Chavagnac et al., 2001; Zheng et al., 2005a, 2006; Liu et al., 2006a; Wu et al., 2006a; Gao et al., 2011). In this study, two different occurrences of G-type eclogite at Bixiling (hosted by granitic orthogneiss) and Shuanghe (hosted by biotite paragneiss) were chosen to evaluate the effect of protolith property on zircon growth. These two outcrops of eclogite-facies rocks experienced the same P–T path of medium-T/UHP metamorphism.

2.1. Bixiling

Bixiling is located at Yuexi County in Anhui Provence, where there is one of the largest outcrops of eclogite in the Dabie orogen (Fig. 1). The Bixiling eclogite ($\sim$1.5 km^2) occurs as a metamorphosed layered intrusion enclosed within granitic gneiss. The outcrop is predominantly composed of banded eclogites that contain thin layers of garnet-bearing cumulate ultramafic rocks, including garnet peridotite, garnet pyroxenite and wehrlite (Fig. 1a). Petrological and geochemical studies have been made on metamafic to metaultramafic rocks (Zhang et al., 1995; Chavagnac and Jahn, 1996; Cheng et al., 2000; Xiao et al., 2000; Zheng et al., 2008). The contact between eclogite and ultramafic rocks is gradational. Field relationships and petrological studies suggest a cumulate origin for premetamorphic mafic–ultramafic complex, indicating their protoliths of intrusive origin. Coesite inclusions were found in omphacite and garnet of the eclogite. According to the mineral assemblages and chemical compositions (Liu et al., 1995), three subtypes of eclogite can be distinguished: high-Ti eclogite (TiO_2 = 3%), high-Mg eclogite (MgO > 10%) and high-Si eclogite (SiO_2 > 50%). Based on the garnet-clinopyroxene Fe–Mg partition geothermometer, the peak eclogite-facies metamorphism occurred at 610–700 °C and >2.7 GPa (Zhang et al., 1995). Amphibolite-facies retrogression is prominent as indicated by symplectites of plagioclase and hornblende after omphacite (Fig. 2a) and