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Metamorphic Dehydration and Partial Melting of Diamond-Bearing Orthogneiss during Continental Subduction-Zone Metamorphism in the Sulu Orogen

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Partial melting of ultrahigh-pressure (UHP) metamorphic rocks has been increasingly recognized in continental collision orogens (Zheng et al., 2011 and references therein). The crustal anatexis generally happened at the exhumation stage of UHP rocks by decompression. As such, the occurrence of anatectic melts dramatically affects the rheology of UHP rocks, facilitating their exhumation (e.g., Hermann et al., 2001; Chopin, 2003; Wallis et al., 2005). In some cases, anatexis could have started at the peak UHP conditions (Labrousse et al., 2011). This hypothesis has been proved to occur in the Sulu orogen, where anatectic zircon contains coesite inclusions (Chen et al., 2013a, b). Petrological and zirconological studies of Gao et al. (2012) and Xia et al. (2013) also suggest anatexis of the continental crust at the transition from HP to UHP eclogite-facies metamorphism during subduction. Therefore, the anatexis of deeply subducted continental crust, especially felsic rocks that are the major component of continental crust, plays an important role in the exhumation of UHP rocks.

It has been a challenge to demonstrate explicitly in petrography that the anatexis of UHP rocks did take place during continental collision, especially for the felsic rocks, because of the back reaction of anatectic felsic melt (Kriegsman, 2001) and extensive retrograde reaction during exhumation (Zheng et al., 2011). Nevertheless, some refractory minerals such as zircon, garnet and allanite can sometimes survive to record the anatectic process. Zircon, a common accessory mineral in high-grade metamorphic rocks, can grow from metamorphic fluid and anatectic melt (e.g., Vavra et al., 1996; Rubatto, 2002; Rubatto et al., 2009; Xia et al., 2009; Chen et al., 2010, 2013a, 2013b; Liu et al., 2010; Li et al., 2013). Due to its robustness, refractory property and extremely low diffusion rates for many elements, zircon can commonly retain its growth age, trace element and isotope signatures even if exposed to suprasolidus temperatures (Cherniak and Watson 2003; Zheng et al., 2004; Scherer et al., 2007). Zirconology, the integrated study of zircon mineragraphy (internal structure and external morphology), U-Pb geochronology, mineral inclusions, trace elements, Ti content thermometer, and Lu-Hf and O isotope compositions, can potentially distinguish anatectic melt from magmatic melt and metamorphic fluid, providing insights into axatexis processes during continental collision.

A combined study of zirconology and petrology was carried out for UHP granitic orthogneiss at Taohang in the Sulu orogen. Tens of samples were collected from this area, but only two representative samples (10SL16 and 10SL38) were used in this study. They are two leucocratic gneisses with a distance of ~100 meters at outcrop. Previous studies have demonstrated that the granitic gneiss and lenticular eclogite in this area have the Neoproterozoic protolith age and experienced the UHP metamorphism together in the Triassic (Yao et al., 2000; Ye et al., 2000; Gong et al., 2007; Nakamura and Hirajima, 2010). The two samples are primarily composed of quartz, plagioclase and phengite with minor amounts of epidote/allanite, garnet, K-feldspar and biotite as well as trace amounts of apatite, zircon, titanite and rutile. The two samples exhibit similarities in rock-forming mineral proportions as well as major and trace element compositions. Anatectic textures of phengite breakdown, K-feldspar cusp or films occur in the both samples. Diamond inclusions were found in metamorphic zircon, confirming that the gneisses did undergo the UHP metamorphism at a mantle depth of >120 km.

An integrated study of zircon U-Pb ages, trace elements and Ti thermometry was performed by means of the in-situ SIMS and LA-ICPMS methods. Zircon in sample-1 (10SL16) records two episodes of new growth in the Triassic: (1) growth from eclogite-facies metamorphic fluid at 236±5 Ma and 630-750℃, with steep REE pattern

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and no Eu anomaly, and few apatite and phengite inclusions; (2) growth from anatectic melt at 223±3 Ma and 700-880℃, with steep REE pattern and marked negative Eu anomalies, higher U, Th, Hf, Y, Ta and Nb contents and few apatite and plagioclase inclusions. In contrast, zircon in sample-2 (10SL38) records protracted growth from metamorphic fluid at 211±3 to 258±5 Ma and 520-670℃ for most mantle domains with shallow REE patterns and indistinctive Eu anomalies, low trace element contents, and apatite, quartz and fluid inclusions. Few mantle domains grew from anatectic melt at 237±3 Ma and 660-720℃, with steep REE patterns and marked negative Eu anomalies, higher trace element contents, and albite, apatite, muscovite and quartz inclusions. Taken together, sample-1 underwent mid-T eclogite-facies metamorphism at 236±5 Ma, whereas sample-2 underwent limited fluid-fluxed melting almost at the same time; sample-1 underwent high-T dehydration melting at 223±3 Ma, whereas sample-2 underwent low-T dehydration throughout the bulk collisional orogeny. In this regard, two episodes of anatexis are evident during continental collision, one at prograde transition from HP-UHP eclogite-facies of 237±3 Ma during subduction and the other at the retrograde transition from HP eclogite-facies to granulite-facies of 223±3 Ma during exhumation.

Garnet is similar in the major element composition of two samples, as $Alm_{40-50}Grs_{32-38}Sps_{8-24}$, but different in their texture. Garnet grains in sample-1 are highly bitty and either surrounded by or filled with K-feldspar films. They are divided into two groups by composition: (1) Garnet-I of high X_{Ca}, low X_{Mn}, high Fe/Mg ratios and flat HREE patterns; (2) Garnet-II of low X_{Ca}, high X_{Mn}, low Fe/Mg ratios and steep HREE patterns. It is possible that the highest X_{Ca} of garnet corresponds to the highest metamorphic pressure and the lowest Fe/Mg ratio corresponds to the highest temperature in UHP granitic gneiss (Carswell et al., 2000). In this regard, Garnet-II would grow at lower pressure and higher temperature than Garnet-I. Partition coefficients of REE are calculated between high-T anatectic zircon domain and Garnet II, yielding consistent results with those grown from granulite-facies melts (Rubatto and Hermann, 2007). Therefore, Garnet-I was consumed in the early melting reaction and Garnet II grew together with zircon and K-feldspar from the melt later. In contrast, garnet grains in sample-2 are relatively complete in texture, exhibiting a large X_{Ca} variation but no significant variations in Fe/Mg ratio, X_{Mn} value and trace element composition. They may either be the relict of protolith magmatic garnet or form during prograde metamorphism without involvement of the melting reaction or back reaction during the limited anatexis.

Epidote/allanite in these two samples also exhibit different textures and compositions. In sample-1, rounded allanite grains are zoned with predominant allanite core and surrounded by thin epidote rims. From core to rim, LREE content decreases and HREE content increases; and thus the REE patterns become flat. Most of the other trace elements also increase as a factor of few to more than one thousand except for Sr, which decreases. The most enriched elements are Rb, K and Nb, which are rich in phengite. This indicates that the allanite was metasomatized by the anatectic melt derived from the phengite breakdown, consistent with the exhumation anatexis (Zheng et al., 2011; Gregory et al., 2012). In sample-2, epidote is predominant, some with minor allanite cores. From core to rim, the trace element shows variations but not systematically, which may be caused by later action of retrograde fluid.

While the growth of metamorphic zircon is temporally associated with fluid action during continental collision, the growth of metamorphic garnet is genetically triggered by breakdown of hydrous minerals such as amphibole, biotite and epidote during subduction-zone metamorphism. As such, the fluid action is a key to the growth of both zircon and garnet in continental subduction channel. The compositional differences in garnet and allanite/epidote between the two samples may be caused by the differences in their P-T paths, which are recorded by the zircons in the two samples. These two distinct P-T paths were also reported by Yao et al. (2000) and Nakamura and Hirajima (2010), respectively. This difference can be explained by the difference in the position of the two samples in the subducted crustal slice during continental collision. The top of subducting slab is colder than its interior because the bottom of mantle wedge above continental subduction channel is much colder than the mantle wedge above the oceanic subduction channel (Zheng, 2012). During the subduction of continental crust toward the mantle depth, different positions of a crustal slice would undergo metamorphism at different P-T conditions, with an increased thermal gradient from top to interior. It is thus expected that sample-1 would be located in the interoir of a crustal slice that experienced the mid-T dehydration metamorphism at the prograde HP to UHP eclogite-facies transition during subduction and then the high-T dehydration melting due to decompressional exhumation. In contrast, sample-2 would lie atop the slice that is prone to fluid focus and thus experienced the protracted low-T dehydration metamorphism with the limited anatexis when the slice was subducted into a depth that meets the wet solidus of granitic rocks. Therefore, the position of crustal slices in the subducting continental crust dictates its dehydration and anatexis at different times and P-T conditions during the collisional orogeny.

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Key words: metamorphic dehydration, partial melting, anatectic zircon, continental collision

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