



Garnet geochemistry records the action of metamorphic fluids in ultrahigh-pressure dioritic gneiss from the Sulu orogen



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ABSTRACT

A combined study of major and trace elements, water content and oxygen isotope composition was carried out for newly grown garnets in ultrahigh-pressure dioritic gneiss from the Sulu orogen. The results indicate the occurrence of a core–rim structure of garnet grains with growth of rims over cores via the mechanism of coupled dissolution–reprecipitation. This provides new insights into the action of geofluids on garnet growth during continental subduction-zone metamorphism. The garnet cores and rims show distinct geochemical compositions. The cores have high spessartine contents (4.2–19.4 mol%), relatively low grossular contents (26.5–29.8 mol%) and low $\delta^{18}\text{O}$ values ($5.0 \pm 0.2\text{‰}$). The rims have relatively low spessartine contents (1.0–3.4 mol%), high grossular contents (28.7–36.1 mol%) and high $\delta^{18}\text{O}$ values ($6.1 \pm 0.3\text{‰}$). Furthermore, the rims show much lower contents of Li and HREE, and considerably higher contents of Sc, V and Ga than the cores. In addition, the cores exhibit very low contents of structural hydroxyl in 32 ± 10 to 48 ± 20 ppm H_2O , whereas the rims show much higher contents of structural hydroxyl in 112 ± 16 ppm to 171 ± 34 ppm H_2O . Although the boundary between core and rim is highly irregular in the garnet grains, the zoning in water contents, element and oxygen isotope compositions are all spatially correlated with each other. Taken all the observations together, it is suggested that the geochemical compositions of garnet cores and rims would be primarily dictated by two types of geofluids with distinctive compositions. Some garnet fragments, bounded by fractures, show the two types of domains with distinct water contents. This difference indicates insignificant exchange of structural hydroxyl by diffusion during growth of the rims over the cores. Mineral-pair O isotope thermometry yields consistent temperatures of ~ 550 °C for the quartz–garnet rim and quartz–titanite, and titanite U–Pb dating yields a metamorphic age of 226 ± 6 Ma. Thus, the growth of garnet rims is linked to the action of geofluids (probably anatectic melts) during the exhumation of deeply subducted continental crust. Therefore, the compositions of garnet cores and rims are primarily controlled by the composition of attending fluids. As such, garnet provides a mineralogical record of the fluid action during subduction-zone metamorphism.

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1. Introduction

Fluids play an important role in subduction-zone metamorphism (e.g., Peacock, 2003; Manning, 2004; Ernst and Liou, 2008; Zheng, 2009; Hermann et al., 2013). They can catalyze mineral reaction, enhance trace element mobility and fractionation, facilitate mass transfer at the slab–mantle interface in subduction channels (e.g., Austrheim, 1987; John et al., 2004; Halama et al., 2011; Zheng, 2012; Vrijmoed et al., 2013). Therefore, it is important to elucidate the source and composition of subduction-zone fluids, the timing and P–T conditions of fluid action, and the geochemical and geodynamic consequences for

the fluid–rock interaction in both oceanic and continental subduction zones (e.g., Villa and Williams, 2013; Zheng and Hermann, 2014).

Fluids attending high-pressure (HP) and ultrahigh-pressure (UHP) metamorphism can be recorded in the fluid inclusions of metamorphic and anatectic minerals and the fluid-precipitated quartz veins in HP and UHP metamorphic rocks (e.g., Xiao et al., 2000; Scambelluri and Philippot, 2001; Fu et al., 2002; Gao et al., 2007; Zheng et al., 2003a, 2007; Zhang et al., 2008; Chen et al., 2012; Zheng and Hermann, 2014). In addition, fluid–rock interaction can significantly modify the geochemical compositions of subducted crustal rocks and their constituent minerals (e.g., Sheng et al., 2012; Errico et al., 2013; Sheng et al., 2013; Chen et al., 2014). Therefore, it is important to decode the nature of subduction-zone fluids at subarc depths of >80 km (Zheng and Hermann, 2014). Although subduction-zone fluids are usually not available for direct analysis, their action can be indirectly deduced from

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geochemical analyses of the metamorphic and anatectic minerals that grow from or are altered by the fluids (e.g., [Erambert and Austrheim, 1993](#); [Rubatto and Hermann, 2003](#); [Martin et al., 2008](#); [Chen et al., 2011a,b](#); [Martin et al., 2011](#); [Page et al., 2013](#)).

Garnet is a versatile mineral that can be used to constrain the pressure, temperature and time (P–T–t) of subduction-zone metamorphism (e.g., [Xia et al., 2012](#); [Baxter et al., 2013](#)). Furthermore, it can be used to decode the action of subduction-zone fluids during HP and UHP metamorphism (e.g., [Erambert and Austrheim, 1993](#); [Dragovic et al., 2012](#); [Baxter and Caddick, 2013](#); [Page et al., 2013](#); [Martin et al., 2014](#)). Thermodynamic modeling suggests that prograde garnet growth can be linked to the breakdown of hydrous minerals ([Hacker et al., 2003](#); [Baxter and Caddick, 2013](#)). Thus, the abundance, P–T path and growth chronology of garnet can be used to decode dehydration processes during subduction-zone metamorphism.

Garnet can grow by prograde dehydration reactions under different P–T conditions in a closed system (e.g., [Kohn et al., 1993](#); [Carswell et al., 2000](#)). It can also grow or recrystallize if interacting with external metamorphic fluids in an open system (e.g., [Chamberlain and Conrad, 1991](#); [Young and Rumble, 1993](#); [Skelton et al., 2002](#); [Errico et al., 2013](#)). In either case, attending fluids are usually not equilibrated with precursor assemblages, resulting in the dissolution of primary garnet grains and subsequent reprecipitation and overgrowth of new garnet domains (e.g., [Erambert and Austrheim, 1993](#); [Putnis, 2002, 2009](#); [Martin et al., 2011](#)). The fluid–garnet interaction may leave records in both element and isotope compositions, depending on the composition of attending fluids (e.g., [Vielzeuf et al., 2005](#); [Martin et al., 2011](#); [Errico et al., 2013](#); [Page et al., 2013](#); [Martin et al., 2014](#)). In addition, the fluid-altered garnet domains are expected to have higher water contents than unaltered domains.

In order to constrain the role of geofluids during continental subduction-zone metamorphism, garnets with a core–rim structure from UHP dioritic gneiss in the Sulu orogen were studied in detail for their major and trace element compositions, structural hydroxyl contents and oxygen isotope compositions. The results provide the

distinction between the two types of garnet domains that would have grown in association with different compositions of geofluids. In combination with the titanite U–Pb dating, we have decoded the timing of fluid action on the garnet growth during the continental subduction-zone metamorphism.

2. Geological setting and samples

The Sulu orogen is the eastern part of the Dabie–Sulu orogenic belt in east-central China ([Fig. 1](#)), formed by the northward subduction of the South China Block beneath the North China Block in the Triassic (e.g., [Liou et al., 2009](#); [Zheng et al., 2009](#)). This orogen is bounded by the Jiashan–Xiangshui fault to the south and the Wulian–Yantai fault to the north, and segmented into a number of slices by several faults subparallel to the Tan–Lu fault ([Xu et al., 2006](#)). Based on field observations and petrological studies, it is divided into HP and UHP metamorphic zones, both of which are unconformably overlain by the Jurassic clastic strata and the Cretaceous volcanoclastic cover, and intruded by Mesozoic granites. The HP zone in the south is primarily composed of schist, paragneiss, orthogneiss and marble. The UHP zone in the north is primarily composed of orthogneiss and paragneiss, with minor amounts of eclogite, garnet peridotite, quartzite and marble.

The eclogite in the Sulu orogen is mostly enclosed in the granitic gneiss, but some occurs together with the marble and garnet peridotite. Coesite was identified in eclogite and its country rocks, indicating in situ UHP metamorphism for these rocks (e.g., [Liu and Liou, 2011](#)). The UHP rocks in the Sulu orogen experienced peak metamorphism at 3.0–4.5 GPa and 730–850 °C ([Zhang et al., 1995](#); [Liu and Liou, 2011](#)). The UHP metamorphism occurred at 240–225 Ma with duration of 15 ± 2 Myr in the coesite stability field ([Zheng et al., 2009](#); [Liu and Liou, 2011](#)). Most of the UHP rocks have igneous protolith of middle Neoproterozoic age ([Zheng et al., 2004a](#); [Tang et al., 2008a,b](#); [Zheng et al., 2009](#); [Fu et al., 2013](#)). Many of the UHP rocks underwent partial melting during exhumation of the deeply subducted continental crust ([Chen et al., 2013a,b,c](#)).

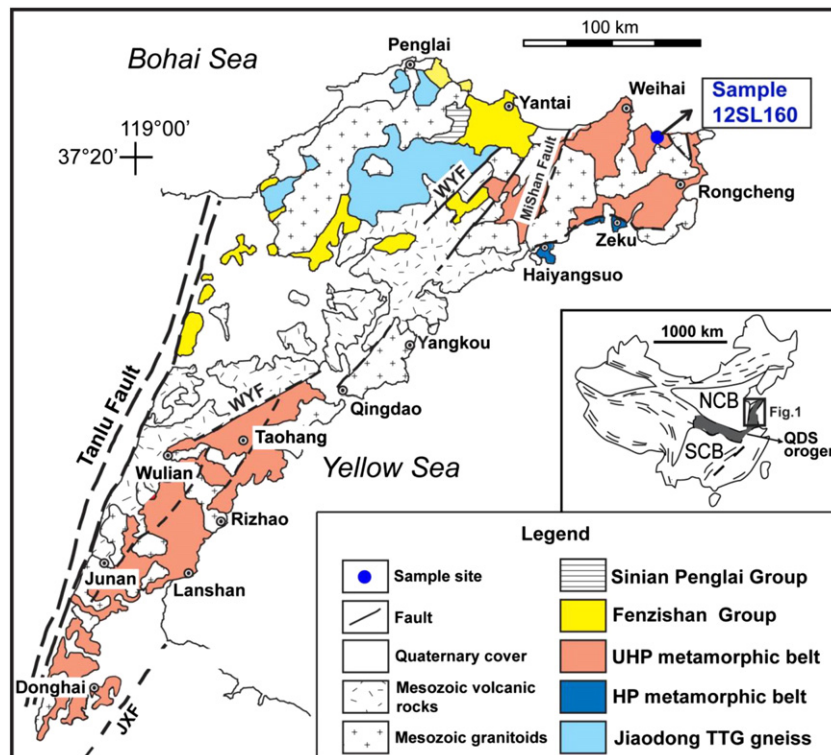


Fig. 1. Geological sketch map of the Sulu orogen. The major lithotectonic units and sample locations are shown. Abbreviations: WYF, Wulian–Yantai fault; JXF, Jiashan–Xiangshui fault; QDS, Qinling–Dabie–Sulu.

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