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Partial melting of UHP calc-gneiss from the Dabie Mountains

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ABSTRACT

Exhumation melting has been proposed for the ultra-high pressure (UHP) metamorphic rocks in the Dabie Mountains based on melting experiments. We document here the first petrological and mineralogical evidence demonstrating that the UHP calc-gneisses from the Ganjialing area in the Dabie Mountains experienced partial melting during early exhumation. The assemblage of garnet, phengite (Si = 3.65 pfu), coesite, rutile and carbonate preserved in the calc-gneisses indicates a peak metamorphic condition of 692–757 °C and 4.0–4.8 GPa. Partial melting is indicated by several lines of evidence: the melting textures of phengite, the feldspar-dominated films, bands, branches, blebs and veins, the euhedral K-feldspars, the intergrowth film of plagioclase and K-feldspar, the plagioclase + biotite intergrowth after garnet and the epidote poikiloblasts. Polyphase inclusions in garnet are characterized with wedge-like offshoots and serrate outlines whereas those in epidote display negative crystal shapes, which can be best interpreted by entrapment of former melts. We propose a wet melting reaction of Phn + Q ± Na-Cpx + H_2O = Bt + Pl + Grt + felsic melts, which likely took place at ca.650–800 °C and ca.1.0–2.0 GPa, to interpret the melting event in the calc-gneisses. Chemical exchanges between garnet and melts produced new garnet domains with higher almandine, spessartine, MREE, HREE and Y but lower grossular, pyrope, P, Sc, Ti, V and Zr contents. Zr-in-rutile thermometer reveals a low temperature of 620–643 °C at 5 GPa, indicating a later reset for Zr in rutile. Healed fractures are suggested to be responsible for the formation of some polyphase inclusions in garnet.

1. Introduction

Partial melting of ultra-high pressure (UHP) metamorphic rocks has attracted special attention in the last decade (e.g., Chopin, 2003; Zheng et al., 2011), for its significant influence on the chemical and mechanical behaviors of deeply subducting crusts. For example, partial melting and melt migration not only enhance chemical differentiation of subducting crust, but also affect sub-arc magmatic activities (Hermann and Rubatto, 2014). In addition, the presence of melt can greatly reduce the viscosity of UHP rocks (Labrousse et al., 2002, 2011; Vanderhaeghe and Teyssier, 2001a, 2001b) and consequently promotes their rapid exhumation (Ernst, 2006; Whitney et al., 2009).

Some UHP terranes, such as the Kokchetav Massif and the Bohemian Massif (e.g., Massone, 2003; Shatsky et al., 1999), are believed to have experienced peak metamorphic temperatures high enough to trigger dehydration melting during deep subduction. However, most UHP rocks had a relatively cold subduction trajectory that prevents an anatexis under fluid-absent conditions. The presence of water can decrease the solidus of rock systems and favor the production of hydrous melts at much lower temperatures. This melting mechanism has been proposed for the melting phenomena in the Western Gneiss Region (Labrousse et al., 2002, 2011). Another possible melting mechanism for UHP rocks is decompression melting when a nearly isothermal or a heating exhumation path crosses the solidus (Auzanneau et al., 2006; Hermann, 2002; Hermann and Rubatto, 2014; Whitney et al., 2009). Extensive migmatization in the Sulu UHP terrane (Liu et al., 2010a, 2010b, 2012; Wallis et al., 2005; Zong et al., 2010) and the young UHP terrane in eastern Papua New Guinea (Gordon et al., 2012) provides such examples.

Although melting evidence (such as leucosomes) is easy to be recognized in the macro scale, it is more elusive in the micro scale because crystallization of melts and re-equilibration of peak minerals during later retrogression would eliminate the relevant records. During the past years, polyphase inclusions in peak minerals such as garnet and clinopyroxene provide a potential window to trace the melting history of UHP rocks. These inclusions generally show an irregular intergrowth of various daughter minerals, negative crystal shapes and radial wedge-like offshoots, and are interpreted to be trapped supercritical fluids or melts (e.g., Gao et al., 2012; Hwang et al., 2001, 2003; Korsakov and Hermann, 2006; Liu et al., 2013; Stöckhert et al., 2001; Zeng et al., 2009). This interpretation has been confirmed by UHP melting experiments on hydrous and carbonaceous minerals in garnet, which produce not only wedge-like protrusions and thin branches filled by former melts, but also patchy microstructures highlighted by newly growing garnet (Perchuk et al., 2005, 2008a, 2008b). Lang and Gilotti (2007) recognized the patchy microstructures of garnet and some other melting evidence in the UHP metapelites from the northeastern Greenland Caledonides, such as melt films (termed as ‘feldspar moats’ in their paper) and melting reactions between phengite and quartz.

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Evidence has accumulated that the Sulu UHP terrane has experienced extensive partial melting during exhumation (e.g., Chen et al., 2013a, 2013b; Liu et al., 2010a, 2010b, 2012; Wallis et al., 2005; Zong et al., 2010). However, natural evidence of partial melting for the Dabie UHP terrane has been sparse. So far, only felsic polyphase inclusions have been suggested as a melting witness for the UHP eclogites from the Shuanghe area (Gao et al., 2012, 2013; Liu et al., 2013). In this paper, comprehensive petrological and mineralogical evidence is presented to show for the first time that the UHP calc-gneisses from the Ganjialing area in the Dabie UHP terrane underwent partial melting during early exhumation.

2. Geological setting

The Dabie–Sulu orogenic belt in east-central China was built up by the Triassic deep continental subduction of the South China Block beneath the North China Block (Cong, 1996; Liou et al., 1996; Okay, 1993; Zheng et al., 2009) (Fig. 1a). It is separated into two main segments by the huge left-lateral strike-slip Tan-Lu fault, with the Dabie terrane in southwest and the Sulu terrane in northeast. The Dabie terrane comprises a series of fault-bounded metamorphic units that can be divided into five major zones based on the lithotectonic features (Hacker et al., 2000; Zheng et al., 2005). From north to south, they are: (1) the Beihuaiyang greenschist-facies zone, (2) the North Dabie high-T granulite-facies zone, (3) the Central Dabie medium-T/UHP eclogite-facies zone, (4) the South Dabie low-T eclogite-facies zone, and (5) the Susong blueschist-facies zone (Fig. 1b).

The Central Dabie medium-T/UHP eclogite-facies zone includes abundant orthogneisses and moderate paragneisses, eclogites, marbles and minor jadeite quarzites, ultramafic rocks, which are intruded by extensive Early Cretaceous granites. Many UHP index minerals have been discovered in this region, such as coesite and α-PbO_2-type TiO_2 in eclogites (Okay et al., 1989; Wang et al., 1989; Wu et al., 2005), the assemblage of magnesite + aragonite in zircon in marbles (Liu et al., 2006) and magnetite lamellae exsolutions in olivine in ultramafic rocks (Zhang et al., 1999), etc. Although the most abundant gneisses exhibit an amphibolite-facies assemblage, coesite inclusions were also discovered in their zircons (Liu et al., 2001; Ye et al., 2000). This suggests that the whole rock sequence in this region experienced an in-situ UHP metamorphism.

This study focuses on the UHP calc-gneisses from the Ganjialing area, which is located in one marble-paragneiss unit of the Central Dabie medium-T/UHP eclogite-facies zone (Fig. 1c). Our field work reveals that the marbles in these litho-units occur as discontinuous masses in the paragneisses. The marbles are pure to impure in composition and enclose various rocks, such as calc-gneisses, eclogites and clinohumite–diopside–garnet rocks, which mainly present as discontinuous layers and lenses (Fig. 2a). The long axes of lenses are parallel to the lineation, if present, in the host marbles. In contrast to the country paragneisses that have an amphibolite-facies assemblage, all the other rocks preserve their peak UHP assemblages. Various rock veins showing megacrystal texture are observed at this locality, such as mica-rich, amphibole-rich and calcite veins in the marbles, and zoisite, zoisite–quartz and quartz veins in the eclogites. The contacts between these veins and the host rocks are usually sharp. This area has attracted little attention in the past and only peak P–T conditions have been estimated for the eclogites in the marbles (Carswell et al., 1997).

3. Analytical methods

All the analyzing works were conducted at the State Key Laboratory of Geological Processes and Mineral Resources (GPMR), China University of Geosicences (CUG), Wuhan. The polished thin sections were carefully examined for their petrography with optical microscope, laser Raman spectroscopy and back-scattered electron (BSE) imaging in a FEI Quanta 450 field emission gun scanning electron microscope (SEM). Energy dispersive spectroscopy (EDS) was also used for mineral identification in the SEM.

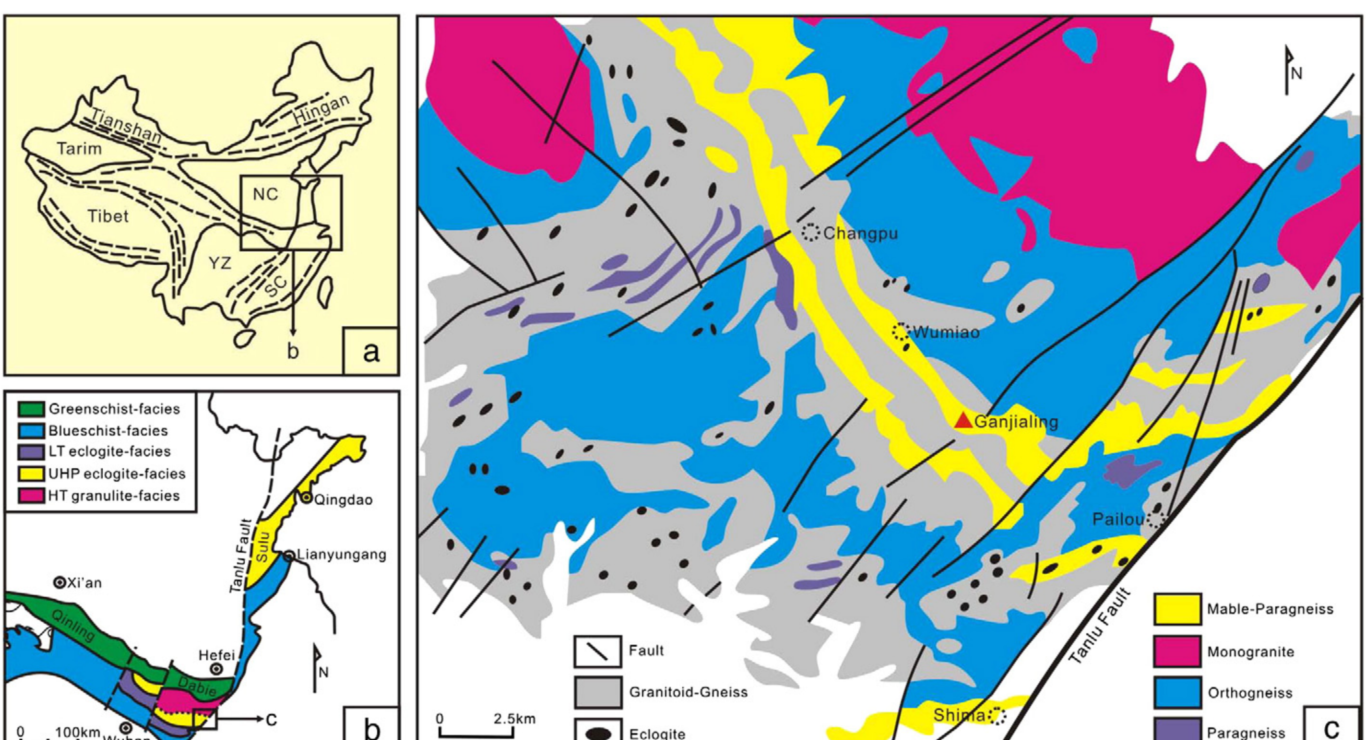

Fig. 1. (a–b) Geological sketch maps of the Dabie–Sulu orogenic belt (modified from Wu et al., 2006). NC—North China block, YZ—Yangtze block, SC—South China block. (c) Geological sketch map of the study area and sample location (modified from Schmid et al., 2000). Note the NW–SE trend of the marble-paragneiss units. Red triangle refers to the sample locality in this study.