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The geochemical characteristics of metabasites with a pseudo-pillow structure from Ganghe, Dabie Orogen, China

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ABSTRACT

Several metabasite lenses in Ganghe, Central Dabie, that were previously described as pillow lavas are studied by elemental, Sr–Nd–Pb isotopic, and mineral oxygen isotopic analysis as well as zircon SHRIMP U–Pb dating. Zircon U–Pb geochronology results indicate that the protolith emplacement age of these metabasites is approximately 717 ± 38 Ma, consistent with the age of the volcanoclastic rocks in the same unit, and that they experienced the Triassic HP eclogite-facies retrograde metamorphism at 221 ± 2 Ma during exhumation after subduction to mantle depth and peak ultra-high pressure metamorphism. The low $\delta^{18}O$ values of −5.5‰ to −2.0‰ indicate that the protoliths underwent high temperature meteoric-hydrothermal alteration before subduction but had no seawater interaction. These metabasites had similar formation processes, water–rock interactions and metamorphisms as other eclogite-facies rocks cropped out in the Central Dabie terrain. They showed negative abnormalities in Nb, Sr, and Ti content and positive abnormalities in Ba, Th, and Pb content; they also showed LREE enrichment. The insusceptible Sm–Nd isotopes during metamorphism yielded $\varepsilon_{Nd}(t) = -12$ to −10 and $T_{DM} = 2.2$–2.8 Ga for samples from lenses #1 to #3 and −7 to −6 and 2.1–2.2 Ga for lens #4; the samples also showed low radiogenic Pb isotope compositions of $(^{206}Pb/^{204}Pb)_i = 15.34$–16.50, $(^{207}Pb/^{204}Pb)_i = 15.23$–15.32, and $(^{208}Pb/^{204}Pb)_i = 35.93$–37.04. The data suggest that the protolith sources of the metabasites were contaminated to variable degrees by old crustal materials during formation. Unlike the Maowu layered intrusions, which were contaminated by upper crust, the magmas of the metabasites were contaminated by lower crust in the magma chamber and during eruption. It can be concluded that the protoliths of these metabasites were derived from old crustal-contaminated mantle sources and initially emplaced in the crust at the Neoproterozoic and that they were altered by meteoric water at high temperatures. In this respect, they might be similar to the Neoproterozoic mafic intrusions in the North Huaiyang terrain. However, the studied metabasites experienced the Permo-Triassic subduction and metamorphism, whereas the North Huaiyang Neoproterozoic mafic intrusions did not.

1. Introduction

It is widely accepted that the Yangtze Block that was subducted northward under the North China craton during the Permo-Triassic (Liu et al., 2008; Cheng et al., 2011) and the Dabie-Sulu Orogen represents a collisional boundary. A previous tectonic model suggested that oceanic crust existed between the two plates before the subduction (Faure et al., 1999). Jahn et al. (1999) also proposed that oceanic crust could be subducted to mantle depth and converted to eclogite-facies rock. Pillow basalts, which are among the most abundant volcanic rocks occurring throughout the geological record, are common on modern ocean floors, in Phanerozoic ophiolites, and in Archean greenstone belts (Polat et al., 2003). Pillow basalts may undergo a series of physical and chemical changes during seafloor hydrothermal alternation after volcanic eruption.

The axiolitic metabasite lenses from Ganghe, Dabie Orogen, have been described as pillow lavas by Oberhänsli et al. (2000, 2002) and Schmid et al. (2003); their petrologic and tectonic characteristics have also been described. The lenses, along with other rocks such as volcanoclastic rock, pelite, and chert, forms the Ganghe complex that overlies the gneissic basement of the Yangtze Block (Schmid et al., 2003). It was suggested that the complex was compatible with formation in a rift setting along a passive continental margin (Schmid et al., 2003). Ames et al. (1996) offered a similar interpretation, suggesting that the rocks of the Dabie Orogen represent a metamorphosed Proterozoic rift sequence. Thus, the pillow lavas in the Ganghe area had been considered to be part of an ocean-continent transfer belt that existed before

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the Permo-Triassic subduction, survived and was exhumed to the crustal level with eclogite-facies rocks after ultra-high pressure metamorphism (UHPM), while most of the oceanic crust was eventually detached from the continental lithosphere (e.g., Jahn et al., 1999). Subduction of continental margin rocks such as pillow lavas may have direct implications for crustal recycling and subsequent crust-mantle interactions. However, Zheng et al. (2003) suggested that the protoliths of most eclogites in Dabie Orogen were continental basaltic rocks. These metabasites, therefore, may offer the opportunity to verify the existence of oceanic crust relic after the subduction.

Because Oberhänsli et al. (2002) and Schmid et al. (2003) already conducted detailed petrologic research on these lenses, this paper attempts to: (1) present new geochemical information on the lenses to identify their material source; (2) compare them to other metabasites with similar histories in the Dabie Orogen; and (3) discuss the progress of crustal-mantle interactions in the north margin of the Yangtze Block.

2. Geologic setting and sample description

The general geology of the Dabie Orogen has been described in numerous publications (e.g., Hacker et al., 1996; Liou et al., 1996; Faure et al., 1999; Zheng et al., 2003; Zhao et al., 2011). The Dabie Orogen is composed of four major petro-tectonic units; from north to south, these are: (1) the North Huaiyang belt (NHY), (2) the North Dabie terrain (NDT) with HT/HP granulite-facies metamorphism, (3) the Central Dabie terrain (CDT) with ultra-high pressure metamorphism (UHPM), and (4) the South Dabie terrain (SDT, formerly the Susong Group) with dominant LT/HP blueschist-facies metamorphism (Fig. 1). These units are bounded in the southwest by the Xiangfan-Guangji Fault, in the east by the Tan-Lu Fault and in the north by the Hefei Basin. The most abundant rocks within the four units are gneisses, and all four units contain Cretaceous igneous rocks.

UHPM rocks occur widely in the Central Dabie and the Sulu terrains. The Sulu unit was offset at least 500 km northward to the Shandong Peninsula along the Tan-Lu Fault. In both regions, numerous coesite- and microdiamond-bearing eclogites crop out within orthogneiss, peridotite, and marble (e.g., Okay et al., 1989; Wang et al., 1989; Xu et al., 1992; Zheng et al., 2011). These observations imply the subduction of supracrustal materials to mantle depths of more than 120 km, then brief recrystallization under UHP conditions, followed by rapid exhumation (Zheng et al., 2003). Geochemical and isotopic studies (Jahn, 1998; Zhang and Liou, 1998) suggested that the protoliths of most eclogites in the Dabie-Sulu terrain were continental basalts and gabbros that exchanged H, O and C isotopes with ancient meteoric water (Zheng et al., 1998, 1999, 2000, 2003; Gao et al., 2011). Eclogite lenses within marble could have been derived from marls or basaltic rocks, which cut the carbonate sediments, and eventually contaminated by calcareous sediments.

Permo-Triassic ages ranging from 255 to 210 Ma have been obtained by zircon U–Pb, mineral Sm–Nd, Ar–Ar, and other isotopic methods for analyzing eclogites and gneisses (Ames et al., 1993, 1996; Li et al., 1993, 1994, 1999, 2000; Okay et al., 1993; Hacker and Wang, 1995; Chavagnac and Jahn, 1996; Rowley et al., 1997; Webb et al., 1999; Hacker et al., 1998, 2000; Ayers et al., 2002; Liu et al., 2008; Zheng, 2008; Cheng et al., 2011). However, the exact timing of the UHPM is still controversial. Based on the zircon U–Pb ages of 210–225 Ma (Ames et al., 1993, 1996; Rowley et al., 1997) and the mineral Sm–Nd isochron ages of 210–226 Ma (Li et al., 1993, 1994, 2000; Chavagnac and Jahn, 1996), some authors considered that the UHP event occurred during the late Triassic. Others have advocated a peak UHPM during the early to middle Triassic based on a few Sm–Nd mineral isochron ages of approximately 245 Ma for eclogites (Li et al., 1993, 2000; Okay et al., 1993), a SHRIMP U–Pb age of approximately 240 Ma on overgrowths of zircon grains in granitic gneisses (Hacker et al., 1998), and zircon and monazite U–Th–Pb ages of 230–237 Ma (Ayers et al., 2002). Zheng (2008) concluded that the UHP metamorphism in the diamond stability field took place at approximately 238–235 Ma and lasted approximately 10 Ma; in this scenario, high-pressure eclogite-facies recrystallization was carried out in 225–215 Ma during exhumation, followed by the amphibolite-facies retrograde metamorphism in 215–205 Ma.

The Ganghe complex occurs in the southwest part of Yuexi county in the CDT. The main rock assemblages in this area are a sequence of metasandstones, coarse- to fine-grained metavolcanoclastic rocks, metacherts, meta-pillow lavas (metabasites), ash beds, metapelites and marls; these rocks represent a metamorphosed cover sequence of the Yangtze Block (Oberhänsli et al.,

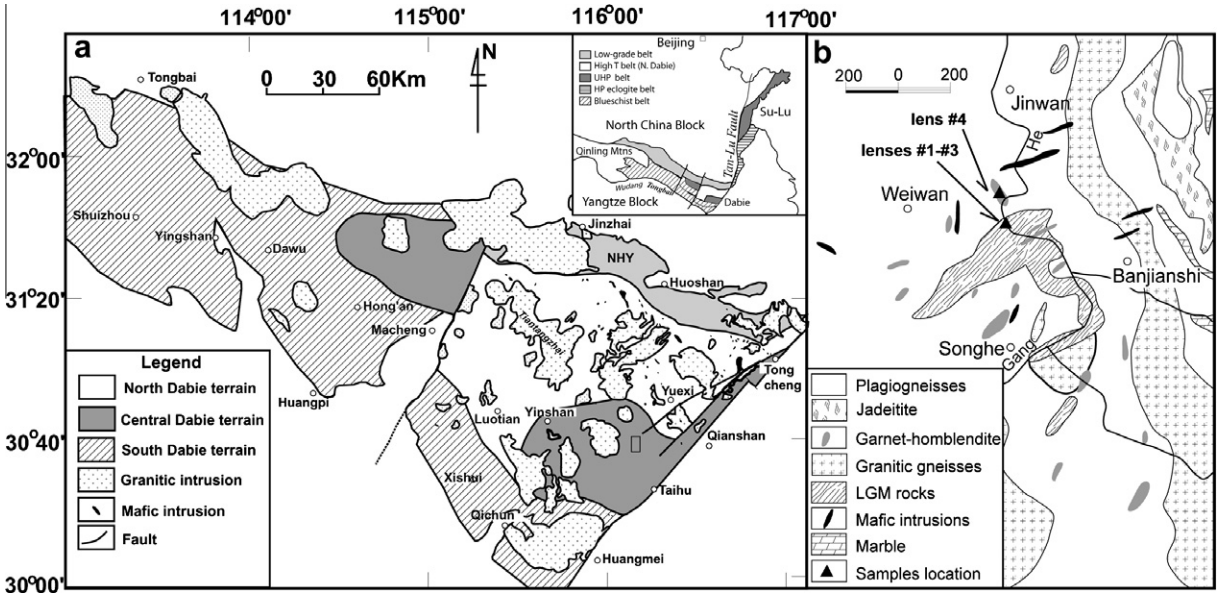

Fig. 1. (a) Sketch map of the Dabie Orogen. (b) Simplified geological map of the Ganghe area, the Dabie Orogen and the sampling location of the lenses (modified from Oberhänsli et al. (2000)).