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Zircon geochemistry of two contrasting types of eclogite: Implications for the tectonic evolution of the North Qaidam UHPM belt, northern Tibet

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ABSTRACT

Compared to the extensively documented ultrahigh-pressure metamorphism at North Qaidam, the pre-metamorphic history for both continental crust and oceanic crust is poorly constrained. Trace element compositions, U–Pb ages, O and Lu–Hf isotopes obtained for distinct zircon domains from eclogites metamorphosed from both continental and oceanic mafic rocks are linked to unravel the origin and multi-stage magmatic/metamorphic evolution of eclogites from the North Qaidam ultrahigh-pressure metamorphic (UHPM) belt, northern Tibet. For continental crust-derived eclogite, magmatic zircon cores from two samples with U–Pb ages of 875–856 Ma have both very high $\delta^{18}O$ (10.6 ± 0.5‰) and mantle-like $\delta^{18}O$ (averaging at 5.2 ± 0.7‰), high Th/U and $^{176}Lu/^{177}Hf$ ratios, and steep MREE-HREE distribution patterns (chondrite-normalized) with negative Eu anomalies. Combined with positive ε_{Hf} (t) of 3.9–14.3 and T_{DM} (1.2–0.8 Ga and 1.3–1.0 Ga, respectively), they are interpreted as being crystallized from either subduction-related mantle wedge or recycled material in the mantle. While the metamorphic rims from the eclogites have U–Pb ages of 436–431 Ma, varying (inherited, lower, and elevated) oxygen isotopes compared with cores, low Th/U and $^{176}Lu/^{177}Hf$ ratios, and flat HREE distribution patterns with no Eu anomalies. These reflect both solid-state recrystallization from the inherited zircon and precipitation from external fluids at metamorphic temperatures of 595–622 °C ($T_{Ti\text{-}in\text{-}zircon}$).
For oceanic crust-derived eclogite, the magmatic cores (510 ± 19 Ma) and metamorphic rims (442.0 ± 3.7 Ma) also show distinction for Th/U and $^{176}Lu/^{177}Hf$ ratios, and the REE patterns and Eu anomalies. Combined with the mantle-like $\delta^{18}O$ signature of 5.1 ± 0.3 ‰ and two groups of model age (younger T_{DM} close to the apparent ages and older >700 Ma), two possible pools, juvenile and inherited, were involved in mixing of mantle-derived magma with crustal components. The relatively high $\delta^{18}O$ of 6.6 ± 0.3‰ for metamorphic zircon rims suggests either the protolith underwent hydrothermal alteration prior to the ~440 Ma oceanic crust subduction, or external higher $\delta^{18}O$ fluid activities during UHP metamorphism at ~440 Ma.
Therefore, the North Qaidam UHPM belt witnesses multiple tectonic evolution from Late Mesoproterozoic–Neoproterozoic assembly/breakup of the Rodinia supercontinent with related magmatic emplacement, then Paleozoic oceanic subduction, and finally transition of continental subduction/collision related to UHP metamorphism.

1. Introduction

High-pressure (HP) and ultrahigh-pressure (UHP) metamorphic rocks in orogenic belts record geodynamic histories of lithospheric subduction and exhumation. Alpine-type (or A-type) and Pacific-type (or B-type) orogenic belts have been classified to describe scenarios of dominated by continental and oceanic lithosphere subduction/exhumation, respectively (Ernst, 1988; Maruyama et al., 1996; Ernst, 2001; Song et al., 2006; Ernst, 2010). The North Qaidam ultrahigh-pressure metamorphic (UHPM) belt is a typical continental subduction/exhumation zone, which is dominated by ortho- and para-gneisses, and minor eclogites and garnet peridotites with coesite and diamond inclusions (see more details in review papers of Zhang et al., 2013; Song et al., 2014a).

Two contrasting types of eclogite, Neoproterozoic continental crust-derived and early Paleozoic oceanic crust-derived, occur at the North Qaidam UHPM belt (Zhang et al., 2013; Song et al., 2014a). For the continental crust-derived eclogite, the tectonic setting is believed to be Neoproterozoic continental-rift setting (J.X. Zhang et al., 2005; Chen et al., 2009), or plume-related flood basalts (Song et al., 2010). Eclogitic zircons from these rocks show Neoproterozoic magmatic cores (807–877 Ma), which indicate the timing of emplacement into the continental crust, while the metamorphic rims record Paleozoic continental deep subduction/collision (~430 Ma) (J.X. Zhang et al., 2005; Chen et al., 2009; Song et al., 2010; J.X. Zhang et al., 2005). The

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oceanic crust-derived eclogite includes the ~445 Ma subduction of early Paleozoic oceanic crust that formed around 520 Ma, and preceded the above continental subduction (G.B. Zhang et al., 2008). A sequence of three types of eclogite (including a coesite-bearing meta-gabbro) from the Shaliuhe oceanic cross-section have cumulate gabbro and MORB geochemical signatures consistent with their being dismembered fragments of subducted oceanic crust (G.B. Zhang et al., 2008, 2009a).

Zircon is often the only mineral to preserve both protolith nature and metamorphic resetting information through cycle of subduction and exhumation process (Rubatto and Hermann, 2007). Combined U–Pb and Lu–Hf isotope investigations are intensively applied geochemical tools in the search for the origin of the igneous zircons (e.g., Nebel et al., 2007). In addition, oxygen isotope analysis for igneous zircons can constrain the oxygen isotope composition during crystallization of the magma (e.g., Lancaster et al., 2009; Fu et al., 2012). Metamorphic recrystallization of igneous zircons can cause the fractionation of trace elements and the resetting of U–Pb and Lu–Hf isotope systems (eg. Rubatto, 2002; Zheng et al., 2005, 2006; Rubatto et al., 2008; Xia et al., 2010; Z.M. Zhang et al., 2014). These processes are generally related to either metamorphic recrystallization (solid-state, replacement, and dissolution) or new metamorphic growth (from aqueous fluid and hydrous melt) (Rubatto et al., 2008; Xia et al., 2009; Chen et al., 2010). The rate of O diffusion in the crystalline zircon is very slow under anhydrous conditions, but it becomes much faster under hydrous conditions (Watson and Cherniak, 1997). Thus, the oxygen isotope system is very sensitive and acts as an indicator for fluid activity during metamorphic recrystallization/new growth.

For continental subduction/exhumation zone, as a paradigm of the plate tectonic theory, a series of tectonic processes were involved from oceanic subduction to continental collision, with the tectonic transition from the ancient subduction of oceanic crust to the subduction of continental crust (Zheng, 2012). However, geological outcomes from such a tectonic transition are poorly studied, because of the rare outcrops of eclogite generated from oceanic basalts in continental collision orogens.

These two contrasting types of continental and oceanic crust-derived eclogites occur together in the North Qaidam UHPM belt provide us an opportunity to unravel the tectonic transition process from oceanic subduction to continental subduction/collision. As above, zircon acts as a mineral container, a chemical tracer and a time capsule in these eclogites, and is retentive of the protolith information. In this paper, we present combined in-situ zircon U–Pb, trace elements and O–Hf isotopes data to further constrain pre-metamorphic evolution and its geological settings, and metamorphic reworking processes of these two contrasting types of eclogite from the North Qaidam, and the implications for tectonic evolution.

2. Geological background and sampling

The Paleozoic North Qaidam UHPM belt lies between the Qaidam and Qilian blocks on the northern margin of the Greater Tibetan Plateau (Fig. 1). The Qaidam Block is a Cenozoic intra-continental basin developed on the basement of Proterozoic Dakendaban Group gneiss (Yin and Harrison, 2000; Liu et al., 2015), which is dominated by metagranitic and metasedimentary rocks. The Qilian Block contains mainly Paleozoic sedimentary rocks with an underlying imbricate thrust belt of Precambrian basement that consists of granitic gneiss, para-gneiss, schist, and marble (Song et al., 2009). The North Qaidam UHPM belt consists of continental crusts and minor mantle rocks. Along this belt, eclogites are found as blocks and interlayers within the predominant ortho- and para-gneisses in several localities (e.g., Yuka, Xitieshan, and Dulan) extending from northwest to southeast for approximately 400 km (Fig. 1b). Garnet peridotite occurs at the Luliang Shan outcrops (Yang et al., 1994; Song et al., 2005, 2006; Yang and Powell, 2008). The UHP metamorphism in the North Qaidam is documented by the occurrence of coesite inclusions in both eclogite and country gneiss and the diamond inclusions in garnet peridotite (Yang et al., 2001; Song et al., 2003a, 2003b, 2005; G.B. Zhang et al., 2009a, 2009b; J.X. Zhang et al., 2009a, 2010; Liu et al., 2012; Zhang et al., 2013; Song et al., 2014a).

In this study, we investigate four eclogite samples from Yuka (sample 9C16, 9C42, and 9C58, continental) and Dulan terranes (5S23, Shaliuhe cross-section, oceanic). The Yuka terrane is located at the western end of the North Qaidam UHPM belt. This terrane is dominated by Dakendaban Group micaschist, and granitic gneisses (J.X. Zhang et al., 2004; Menold et al., 2009), in which eclogites occur as interlayers

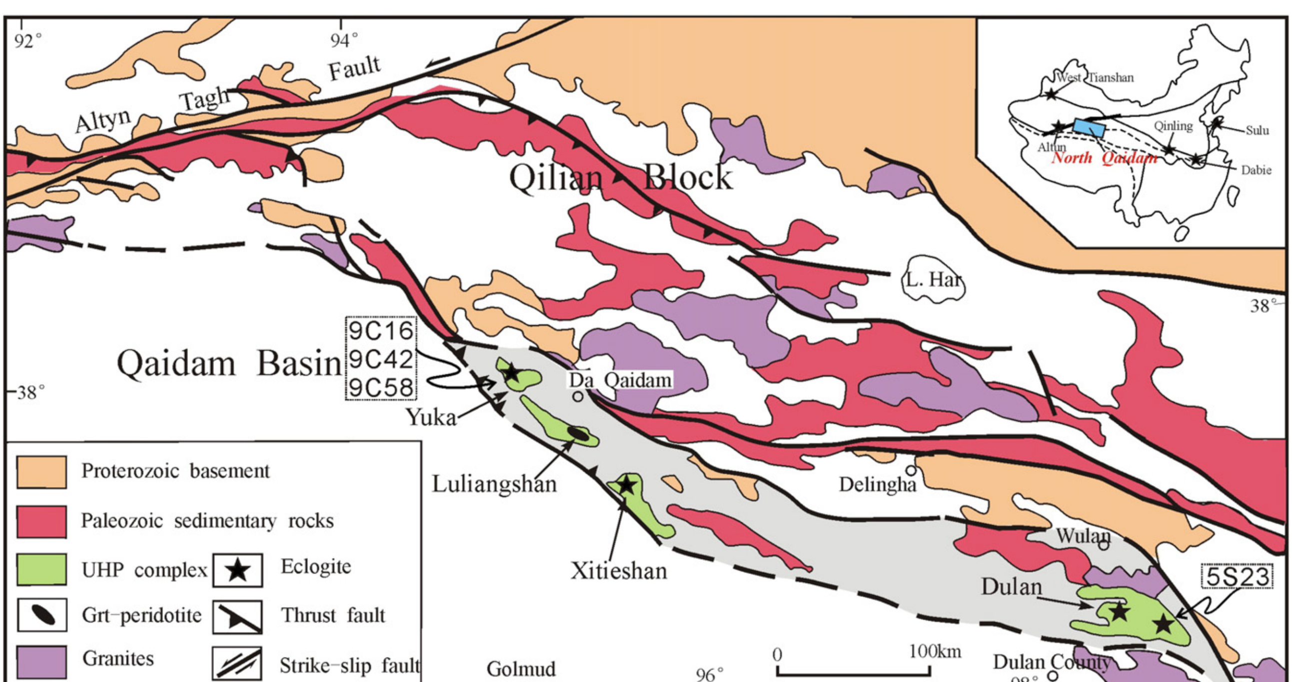

Fig. 1. Geological sketch map of North Qaidam UHPM belt, northern Tibet (after Song et al., 2003a).