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From oceanic subduction to continental collision: An overview of HP–UHP metamorphic rocks in the North Qaidam UHP belt, NW China

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ABSTRACT

The North Qaidam UHPM belt is unique among "continental type" subduction zones in showing well-preserved subducted oceanic relics that predate continental subduction and collision. We review petrologic, thermobarometric, geochemical and geochronological studies for the Yuka, Luliang Shan, Xitieshan and Dulan terranes in this belt. UHP conditions are demonstrated by coesite inclusions in eclogite and country gneiss, and diamond inclusions from garnet peridotite. The relict subducted oceanic lithology crops out in the Shaliuhe cross-section in Dulan terrane; it originated as the floor of a Paleo-Qilian Ocean that existed between Qaidam and Qilian blocks before the early Ordovician. Whereas most eclogites of this belt are derived from mafic rocks of either a Neoproterozoic continental rift or incipient oceanic basin setting, which were subducted along with continental rocks in the early Paleozoic. The data, especially the two protolith sources for eclogites, demonstrate tectonic evolution of the North Qaidam UHPM belt from oceanic subduction to continental collision.

1. Introduction

High-pressure (HP) and ultrahigh-pressure (UHP) metamorphic rocks in orogenic belts record geodynamic histories of lithospheric subduction and exhumation. The terms 'Alpine-type' (or A-type) and 'Pacific-type' (or B-type) orogenic belts have been coined (Ernst, 1988, 2001; Maruyama et al., 1996) to describe scenarios of oceanic and continental lithosphere subduction/exhumation respectively (Song et al., 2006). Oceanic subduction/exhumation zones are characterized by ophiolite mélange, island arc assemblages, and low-temperature/high-pressure metamorphic rock suites, whereas continental subduction/exhumation zones are dominated by granitic gneisses and metasediments with minor eclogites and ultramafic rocks of HP and UHP origin (Zhang et al., 2008c).

More than 20 ultrahigh-pressure metamorphic terranes have been recognized throughout the world so far (Carswell and Compagnoni, 2003; Liou et al., 2004). Only a few of them, such as Zermatt–Saas Zone of the Western Alps (Renecker, 1991; Bucher et al., 2005) and West Tianshan of China (Zhang et al., 2002a,b, 2005c, 2007c), are interpreted to have been formed by deep subduction of oceanic crust sequences. Most of eclogites and ultramafic rocks in UHPM belts are found within continental subduction zones, such as the Dabie-Sulu of China (Jahn, 1999; Zheng et al., 2003) and Western Gneiss Region of Norway (Carswell and Cuthbert, 2003), and show continental crust affinities on the basis of petrology and geochemistry.

The discovery of UHPM coesite (e.g., Yang et al., 2001; Song et al., 2003a) from zircons in paragneisses from the eastern part of the North Qaidam UHPM belt, Western China, and its tectonic implications have been the subject of considerable interest in recent years. The North Qaidam UHPM belt is characterized by its unique tectonic history, which contrasts with those other UHPM terranes in China such as Dabie-Sulu in Eastern China and West Tianshan in Western China. The North Qaidam UHPM belt may record the whole history of oceanic subduction followed by continental subduction and final collision (Song et al., 2006; Zhang et al., 2005a, 2008a,c, 2009c). Thus, the North Qaidam UHPM belt is a natural laboratory to understand the geodynamic process of continental and oceanic subduction and exhumation. In this paper, we review recent progress in the study of North Qaidam UHPM belt over the past 15 years, and discuss tectonic models for this belt.

2. Geological background and research progress of the North Qaidam UHPM belt

The Paleozoic North Qaidam UHPM belt lies between Qaidam and Qilian blocks at the northern margin of the Tibetan Plateau (Fig. 1). The Qaidam block is a Cenozoic intra-continental basin

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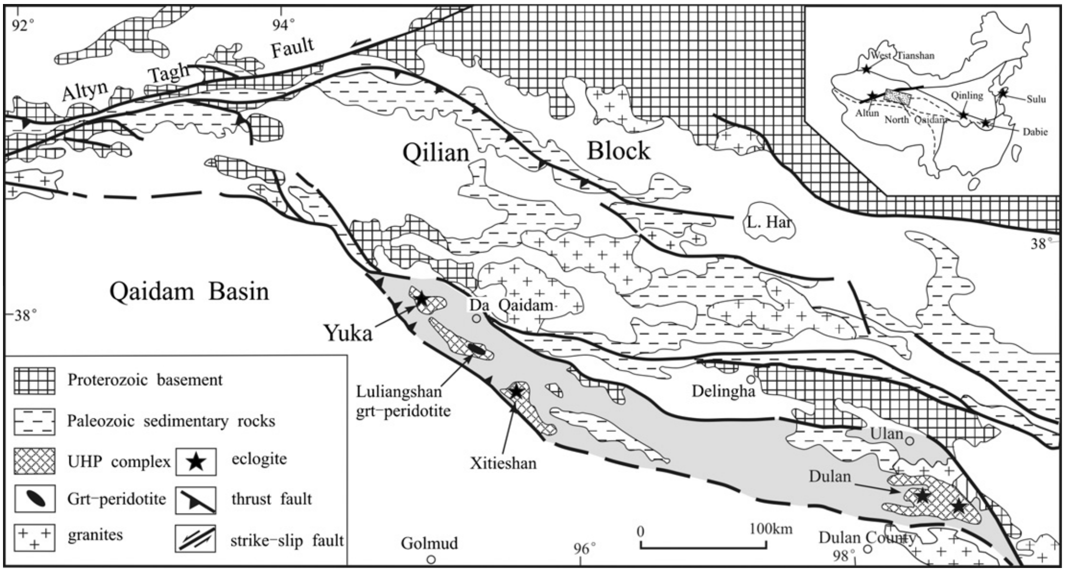

Fig. 1. Geological sketch map showing the distribution of known UHP metamorphic rocks of the North Qaidam UHP metamorphic belt, China (after Song et al. (2003a)).

developed on a Precambrian basement of the Proterozoic Dakendaban Group gneiss (c.f. Yin and Harrison, 2000). The Dakendaban Group gneiss is dominated by metagranitic and metasedimentary rocks. The Qilian block comprises mainly Paleozoic sedimentary rocks underlain by an imbricate thrust belt of Precambrian basement, which consists of granitic gneiss, pelitic gneiss, schist and marble (c.f. Song et al., 2009b). Along the North Qaidam UHPM belt, eclogites are found as boudins and interlayers within para- and orthogneisses in several localities (e.g., Yuka, Xitieshan, and Dulan) extending from northwest to southeast for about 400 km (Fig. 1). Garnet peridotite outcrops occur in the Luliang Shan.

Below, we summarize the evidence for UHP metamorphism in the four terranes (Yuka, Luliang Shan, Xitieshan and Dulan).

2.1. Evidence for UHP metamorphism

The North Qaidam eclogite was discovered by Yang and Deng (1994). A few years later, coesite inclusions were found in zircon from the Dulan paragneiss in the eastern part of this belt (Yang et al., 2001; Song et al., 2003a). This was the first convincing evidence of UHP metamorphism for the North Qaidam. Then, one diamond inclusion was recognized in zircon from the Luliang Shan garnet peridotite (Song et al., 2005). However, for eclogite, only coesite pseudomorphs and exsolved quartz had been found in thin sections at that time (Song et al., 2003a). Recently, coesite inclusions were reported from both eclogite thin sections (Dulan and Yuka) and zircons (Dulan) (Zhang et al., 2009b,c,e, 2010b). Song et al. (2003a) found K-feldspar rich inclusions in Dulan garnets, which were interpreted to be pseudomorphs after the double-layer silicate ''K-cymrite'' ($KAlSi_3O_8{\cdot}nH_2O$), which is known to dehydrate to K-feldspar + aqueous fluid at high pressure (e.g. >2.5 GPa at 600 °C: Hwang et al., 2004 and references therein). The detailed study of Zhang et al. (2009f) verified the presence of ''K-cymrite'' in Dulan eclogite by Raman spectroscopy. Hence, multiple lines of petrographic evidence from the eclogites and peridotites demonstrate that the North Qaidam belt experienced UHP metamorphism. However, we note that no unambiguous UHP record has to date been reported for the granitic gneiss which makes up over 80% of the North Qaidam UHPM belt.

2.2. Yuka

2.2.1. Petrology and thermobarometry

The Yuka terrane is situated 40 km northwest of Da Qaidam town (Fig. 2). This region is dominated by granitic gneisses (Qtz + Pl + Kfs + Czo + Ms) (after Kretz, 1983) and micaschists (Qtz + Phn + Grt + Ky + Pl + Rt) (Zhang et al., 2004; Menold et al., 2009). Two types of eclogite are recognized: coarse- and fine-grained, (Chen et al., 2005; Zhang et al., 2005b; Menold et al., 2007, 2009). The coarse-grained eclogites consist of Grt + Omp + Phn + Coe/Qtz + Rt. Coesite inclusions were found in thin sections of this type of eclogite (Fig. 2; Zhang et al., 2009b). Fine-grained eclogites consist of Grt + Omp + Phn + Ep + Qtz + Rt.

A few *P–T* paths have been determined for both types of Yuka eclogite (Chen et al., 2005; Zhang et al., 2005b, 2009b; Menold et al., 2007). In Fig. 3, we adopt the path 1, which was constrained by two independent studies, and is most consistent with the occurrence of coesite inclusions (Chen et al., 2005; Zhang et al., 2009b). The eclogites experienced three distinguishable metamorphic stages (Chen et al., 2005; Zhang et al., 2009b): (1) a pre-peak metamorphic stage recorded by the mineral assemblage of Amp + Pl + Qtz in the garnet core at P = 0.8–1.0 GPa, T = 450–560 °C for the coarse-grained eclogite and P = 1.0–1.2 GPa, T = 450–510 °C for the fine-grained eclogite, and by the mineral assemblage of Cpx + Phn in the garnet mantle at P = 2.25–2.65 GPa, T = 550–610 °C for the coarse-grained eclogite; (2) the peak stage characterized by the mineral assemblage of Grt + Omp + Phn + Qtz/Coe + Rt at P = 3.01 GPa, T = 652 °C for the coarse-grained eclogite, and Grt + Omp + Phn + Rt + Qtz at P = 2.9–3.2 GPa, T = 566–613 °C for the fine-grained eclogite; and (3) a retrograde stage recorded by the garnet reaction rims, the breakdown of omphacite, and the pervasive retrograde mineral assemblage of Grt + Amp + Pl + Qtz at P = 0.7–1.1 GPa, T = 550–590 °C for the coarse-grained eclogite. The coesite inclusions and the calculated *P–T* paths suggest that the Yuka UHPM terrane experienced deep subduction (~100 km) at a cool geothermal gradient (6–7 °C/km) (Zhang et al., 2009b). Relict high-pressure inclusions (Ky, Phn and Rt) and calculated conditions of garnet growth suggest that the country orthogneiss followed a metamorphic *P–T* path similar to that of the eclogite it encloses, with peak pressure at ~2.6 GPa, very close to the quartz–coesite phase boundary (Menold et al., 2009).