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A polyphase metamorphic evolution for the Xitieshan paragneiss of the north Qaidam UHP metamorphic belt, western China: In-situ EMP monazite- and U–Pb zircon SHRIMP dating

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ABSTRACT

In-situ electron microprobe (EMP) U–Th–Pb monazite-, sensitive high-resolution ion microprobe (SHRIMP) zircon analyses, metamorphic phase equilibrium (Domino/Theriak)- and geothermobarometric calculations are performed on kyanite/sillimanite-bearing garnet biotite gneisses forming part of the dominant rock association in the Xitieshan ultra-high pressure metamorphic belt, north Qaidam, western China. Results are consistent with the following complex polyphase tectono-metamorphic evolution.

The kyanite/sillimanite bearing garnet biotite gneisses contain monazite ages of 938 ± 23 Ma and zircon SHRIMP ages of 945 ± 7 Ma, referring to a Neoproterozoic metamorphism, i.e. similar to the age of the Jinning orogeny in the Yangtze block of southern China. This correlation suggests that the paragneiss has affinities with the Yangtze block (South China block). The Neoproterozoic monazites were found inside coarse grained porphyroblastic garnets containing amphibolite facies mineral inclusion assemblages.

The kyanite/sillimanite-bearing garnet biotite gneisses also contain early Paleozoic monazite ages of 422–425 Ma and 455–460 Ma, detected in amphibolite facies mineral assemblages associated with matrix minerals. Using phase equilibrium- and geothermobarometric calculations, PT conditions of 560–610 °C/5.8–7.0 kbar and 610–675 °C/4.6–6.5 kbar were calculated respectively for both amphibolite facies assemblages. The early Paleozoic ages of 422–425 Ma and 455–460 Ma were detected in 8 monazite grains from the investigated paragneiss samples. Based on the Y and Eu contents variation of the early Paleozoic monazite domains (measured by EMP), the 422–425 Ma monazite ages are interpreted to have formed during an amphibolite facies tectono-metamorphic overprint that post-dates (U)HP metamorphism and can thus be related to exhumation of previously deeply subducted rocks. Alternatively, the 455–460 Ma monazite ages are interpreted to represent the age of the prograde subduction zone metamorphism.

We conclude therefore that the mineral assemblage of the kyanite/sillimanite-bearing garnet–biotite gneiss (and associated retro-eclogite) was formed during an early Paleozoic subduction/collision event, which involved late Proterozoic (938–945 Ma) crystalline basement inliers of minimal mid amphibolite facies grade. Early Paleozoic deep subduction towards (U)HP depths occurred around 455–460 Ma followed by retrograde amphibolite facies metamorphism at 422–425 Ma during exhumation.

1. Introduction

Polyphase tectono-thermal events have been reported from several (U)HP metamorphic belts in the world such as the Alps (Lardeaux and Spalla 1991; Rubatto et al., 2003) and the Scandinavian Caledonides (Brueckner and Van Roermund, 2004). Another good example is described here from the north Qaidam orogenic belt in NW China where a rock association that consists of eclogite and its country rock gneiss (i.e. para- and orthogneisses) defines a natural laboratory where the polyphase metamorphic evolution of an (U)HP terrane can be investigated.

In the north Qaidam UHP metamorphic belt, eclogite and garnet peridotite were discovered only in the last decades (Yang et al., 1994, 1998, 2001), subsequently followed by detailed studies of its petrology (e.g. Song et al., 2003a,b; Zhang et al., 2005, 2009a,b), geochemistry (e.g. Song et al., 2007; Zhang et al., 2003) and geochronology (e.g. Mattinson et al., 2006a,b; Song et al., 2005, 2006; Zhang et al., 2006, 2008a, 2009c, 2010, 2011), leading to a better understanding of the physical conditions during subduction/collision, the nature of the colliding blocks and/or the timing and duration of this early-Paleozoic UHP tectono-metamorphic event. To constrain the age of the (U)HP metamorphism, thousands of eclogitic zircons were dated using different techniques

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(SHRIMP, thermal ionization mass spectrometry (TIMS) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS)). Metamorphic zircons from associated para- and orthogneisses were also investigated (Zhang et al., 2006, 2008b, 2009c). Some of these zircons revealed distinct age domains with Proterozoic (890 ± 14 Ma) ages in their cores and early Paleozoic ages (437 ± 16 Ma) in their rims. The latter are interpreted to represent metamorphic events related to subduction and/or collision (e.g. Zhang et al., 2008b). However, metamorphic mineral assemblages and/or estimates of PT conditions related to the late Proterozoic orogenic events have not been reported from the Qaidam orogen.

In addition, U–Pb zircon ages from single terrane like the Yuka or Xitieshan terranes (Chen et al., 2007; Zhang et al., 2005, 2011) are interpreted in different ways, creating confusion about the timing and duration of subduction, collision and exhumation processes in the north Qaidam (U)HP metamorphic belt. Most probably, this is due to the lack of index minerals that were found as inclusions in zircon and/or lack of other mineral–chemical indicators. To understand the geodynamic significance of various tectono-metamorphic events that affected the north Qaidam area (here defined in terms of its present geographical coordinates) during the late Proterozoic and early Paleozoic eras, it is of crucial importance to investigate the nature and protolith ages of eclogite and associated ortho- and paragneisses that together form the most dominant rock association in the north Qaidam UHP metamorphic belt. In this respect, special attention is paid to the paragneiss including its relationship with associated eclogite in this paper. Knowledge of the precise timing of the growth of accessory minerals, like monazite and zircon, provides crucial information about the spatial and temporal distribution of the various orogenic events that together shaped this polyphase tectono-metamorphic terrane.

Monazite is a light rare earth element (REE) phosphate [(La, Ce, Nd) PO_4] that may incorporate during growth significant amounts of Th and U into its crystal-structure (Williams et al., 2007). It is a common accessory mineral that is present in amphibolite- to granulite-facies metamorphic rocks with leucocratic to pelitic composition (Chang et al., 1996; Overstreet, 1967; Spear and Pyle, 2002). It is highly suited for geochronology because it excludes common Pb during growth, is resistant to diffusive Pb-loss and resilient to radiation damage (Cherniak et al., 2004; Seydoux-Guliiaume et al., 2002). These properties make monazite an important tool that can be used for geochronological studies concerned with timing and duration of medium- to high grade metamorphic belts, most particular polyphase metamorphic terranes (Catlos et al., 2002; Dewolf et al., 1993; Gibson et al., 2004; Kohn and Malloy, 2004; Stern and Berman, 2000). In-situ EMP monazite analyses (chemical age dating) links monazite geochronology to the microstructure (or metamorphic texture) and mineral assemblage of the rock and thus allows to determine the (re)crystallization age of the stable metamorphic mineral assemblage associated with the growth of monazite and/or its recrystallization. In addition, the REE chemical composition of the monazite, also obtained by EMP analyses, can be used to interpret the monazite age with respect to the ages of associated mineral assemblages in a polyphase metamorphic terrane. An example of this is given in this paper.

In this contribution, U–Pb ages obtained by in-situ EMP (monazite)- and SHRIMP (zircon) analyses from a kyanite/sillimanite-bearing garnet biotite gneiss are combined with metamorphic phase equilibrium and geothermobarometric calculations in the same rock. To test the large scale regional implications of our work, EMP monazite ages of two additional paragneiss samples are also included. Results indicate that (minimal) two amphibolite facies metamorphic events affected the Xitieshan terrane. The first tectono-metamorphic event is of Neoproterozoic age and defined by a mineral inclusion assemblage present inside coarse-grained porphyroblastic garnet crystals. The second event is of early Paleozoic age and corresponds to the matrix mineral assemblage of the investigated gneiss samples. In addition, we present evidence that the second amphibolite facies mineral assemblage can be interpreted as a retrograde mineral assemblage of the previous (U)HP mineral assemblage which was formed in early Paleozoic age. It is inferred that similar results can be applied to most paragneisses of the Xitieshan terrane, NW China.

2. Geological setting

The north Qaidam (U)HP metamorphic belt is located in the northwest part of China and is bounded by the Qaidam block to the southwest and the Qilian block to the northeast, it is offset by the sinistral Altyn–Tagh fault in the northwest (Fig. 1A and B). The southern Qaidam block is composed of Precambrian crystalline basement (0.8–1.0 Ga) discordantly overlain by Cenozoic sediments. Alternatively, the northern Qilian block consists predominantly of Precambrian orthogneiss, paragneiss, schist and marble, discordantly overlain by Paleozoic sedimentary rocks (Wan et al., 2001). It was previously considered to represent a continental fragment which was drifted away from the North China Craton (NCC). However, more recent geochronological data has demonstrated that some protoliths of the Qilian crystalline basement were formed around ca. 900–1000 Ma, indicating close affinity with the Yangtze block (South China block, Wan et al., 2001, 2006).

The basement of the north Qaidam (U)HP orogenic belt mainly consist of orthogneiss, paragneiss, amphibolite and marble. They are in discordant contact with the overlying Paleozoic volcanic and sedimentary rocks of Tanjianshan Group. In the north Qaidam orogenic belt, locations of eclogite and garnet peridotite have been discovered near Dulan, Yuka, Xitieshan and Lüliangshan together covering a distance of near 400 km along strike (Fig. 1; Yang et al., 1994, 1998, 2001, 2002). The eclogite and garnet peridotite occur as boudins, layers or lenses intercalated within the host ortho- and/or paragneiss. Based on this rock assemblage, their mutual field relationships and various other petrological and geochronological characteristics, the north Qaidam UHP orogenic belt is interpreted to have formed during an early-Paleozoic collision event between two adjacent continental blocks (here called the Qilian- and Qaidam blocks) with ongoing subduction, eduction and further collision along its suture (Song et al., 2003a,b, 2006, 2009; Yang et al., 2001).

Based on the occurrence of eclogite and garnet peridotite, four (U)HP terranes have thus far been identified in the north Qaidam orogenic belt. From east to west, these are called the Dulan eclogite-bearing terrane, the Xitieshan eclogite-bearing terrane, the Lüliangshan garnet peridotite-bearing terrane and the Yuka eclogite-bearing terrane (Fig. 1B). Although spatially situated in the same orogenic belt, the four (U)HP terranes differ mutually from each other either in the detailed shape of their PT path or in the age of this metamorphism (e.g., Mattinson et al., 2006a; Menold et al., 2009; Song et al., 2003a, 2006). For instance, the PT path of eclogite in the northern part of the Dulan terrane is characterized by near adiabatic decompression from eclogite- to amphibolite facies conditions. In contrast, the heating has occurred during decompression resulting in a granulite-facies metamorphic overprint in the southern part of the Dulan terrane (Song et al., 2003a; Yang et al., 2002; Zhang et al., 2008a). U–Pb dating of metamorphic zircons from eclogite and coesite-bearing paragneiss of the Dulan terrane yields two distinct age ranges: 440–460 Ma and ca. 420 Ma respectively (Mattinson et al., 2006a; Song et al., 2003b, 2006; Zhang et al., 2008a, 2009c). The above mentioned subdivision between northern and southern domains has not yet been implemented in the latter studies.

Eclogite in the Xitieshan terrane experienced isothermal decompression from eclogite- to high amphibolite facies, followed by cooling and decompression to low amphibolite-facies conditions (Zhang et al., 2009a, 2011). Zircon U–Pb dating of Xitieshan eclogite yields two distinct age ranges: 440–460 Ma (Zhang et al., 2011) and ca. 480 Ma; both interpreted to be the age of eclogite facies metamorphism (Zhang et al., 2005, 2006).