Precambrian Research 291 (2017) 42–62

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

# Paleoproterozoic granulite-facies metamorphism and anatexis in the Oulongbuluke Block, NW China: Respond to assembly of the Columbia supercontinent

Shengyao Yu [a,b,c,*], Jianxin Zhang [d], Sanzhong Li [a,b], Deyou Sun [c], Yunshuai Li [e], Xin Liu [a,b], Lingli Guo [a,b], Yanhui Suo [a,b], Yinbiao Peng [d], Xilin Zhao [f]

[a] Key Lab of Submarine Geosciences and Prospecting Techniques, MOE and College of Marine Geology, Ocean University of China, Qingdao 266100, China
[b] Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266061, China
[c] College of Earth Sciences, Jilin University, Changchun 130061, China
[d] Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China
[e] Institute of Surface-Earth System Science, Tianjin University, Tianjin 300072, China
[f] Nanjing Center China Geological Survey, Nanjing 210016, China

A R T I C L E I N F O

*Article history:*
Received 20 October 2016
Revised 18 January 2017
Accepted 22 January 2017
Available online 25 January 2017

*Keywords:*
Oulongbuluke Block
Granulite
Metamorphism
Anatexis
Columbia supercontinent

A B S T R A C T

The Oulongbuluke Block, which is located in the northeastern margin of the Tibet Plateau, has traditionally been considered to be a fragment of the Tarim Craton. Here we present a systematic petrologic, geochemical, and zircon U-Pb and Hf isotopic investigation on mafic granulite and migmatite in the Oulongbuluke Block. The mafic granulite is mainly composed of clinopyroxene, orthopyroxene, plagioclase, amphibole and quartz, with peak metamorphic P-T contions of 6.5–8.8 kbar, 745–770 °C. Macroscopic and microscopic observations provide strong evidence for *in situ* partial melting of the felsic gneiss involving breakdown of biotite within the Oulongbuluke Block. The Pl-rich leucosomes with positive Eu anomalies and higher Sr contents were generated as the early-formed feldspar cumulate, and the Kfs-rich pegmatite with negative Eu anomalies and lower Sr contents may represent percolating fractionated melt that was trapped during cooling. Zircon U–Pb dating and Hf isotopic analyses on the mafic granulite and migmatite of the Oulongbuluke Block reveal two distinct age populations: the early Paleoproterozoic (~2.37 Ga) and late Paleoproterozoic (1.93–1.92 Ga). The ~2.37 Ga magmatic zircon cores of the migmatite have $\varepsilon_{Hf}(t)$ values between −4.3 and 0.4, with two-stage Hf model ages ($T_{DMC}$) mainly between 2.82 Ga and 3.05 Ga. The age of 1.93–1.92 Ga obtained from the mafic granulite and migmatite is interpreted as the age of Late Paleoproterozoic metamorphism and anatexis. Most of the 1.93–1.92 Ga metamorphic and anatectic zircons have significantly lower $^{176}Lu/^{177}Hf$ ratios but higher $^{176}Hf/^{177}Hf(t)$ values than the inherited magmatic zircon cores, which demonstrates that both the zircon U–Pb and Lu–Hf isotope compositions were significantly reset during metamorphism and anatexis. The late Paleoproterozoic metamorphic and anatectic event coincided with global orogenic events that are recorded in many continental fragments, which suggests their link to the Columbia supercontinent.



## 1. Introduction

During the Earth's long geological evolution, several well-defined supercontinents are thought to have formed from the assembly of almost all existing continental fragments, such as Columbia (2.1–1.8 Ga), Rodinia (1100–750 Ma) and Pangaea (350–165 Ma) (Hoffman, 1991; Moores, 1991; Dalziel, 1995; Park et al., 1995; Rogers, 1996; Li et al., 1999, 2004, 2008; Pesonen et al., 2003). Among these supercontinents, reconstructions of Columbia are limited by the fact that Precambrian paleomagnetic data show a large scatter of poles and have poor age constraints (Buchan et al., 2001; Meert, 2002; Rogers and Santosh, 2002; Zhao et al., 2002). Global-scale 2.1–1.8 Ga collisional orogens occur on almost all of the world's cratons, which together represent the assembly of Columbia (Condie, 2002; Zhao et al., 2003, 2004; Hou et al., 2008; Santosh, 2010). Therefore, the identification of Paleoproterozoic collisional orogens and related magmatic and

* Corresponding author at: Key Lab of Submarine Geosciences and Prospecting Techniques, MOE and College of Marine Geology, Ocean University of China, Qingdao 266100, China.
*E-mail address:* yushengyao@ouc.edu.cn (S. Yu).

http://dx.doi.org/10.1016/j.precamres.2017.01.016
0301-9268/

metamorphic rocks is crucial to reconstructing the configuration of the Columbia supercontinent (Santosh, 2010; Long et al., 2011).

China mainly consists of three Precambrian cratons (the North China Craton, the South China Craton and the Tarim Craton) that amalgamated along Phanerozoic orogenic belts (e.g., Zhao et al., 1998, 2001, 2005; Zhai et al., 2005; Lu et al., 2008). Several Precambrian tectonic events related to the assembly of Columbia have been recognized in these cratons: e.g. Paleoproterozoic subduction–accretion–collision tectonics during ca. 1.95–1.82 Ga in the North China Craton (NCC) (e.g., Zhao et al., 2002, 2004, 2005; Zhai and Santosh, 2011 and references) and 1.85–1.82 Ga HP granulite-facies metamorphism and magmatism in the Tarim Craton (TC) (Zhang et al., 2012, 2013). Several micro-continental Blocks have been identified in the domain between southwest NCC and Southeast TC, including the Qilian Block, Oulongbuluke Block (also called the Quanji Block) and Qaidam Block (Chen et al., 2013). Among these, the Oulongbuluke Block is composed of Paleoproterozoic medium- to high-grade metamorphosed crystalline basement and unmetamorphosed cover that represent a cratonic continental remnant (Lu, 2002; Chen et al., 2012, 2013). Several studies have suggested that the Oulongbuluke Block has a similar tectonic evolution history similar to the TC and NCC based on magmatic intrusion and amphibolite-facies metamorphism during the Neoarchean and Paleoproterozoic times (Chen et al., 2012, 2013; Wang et al., 2015). However, compared to the three Precambrian cratons (the NCC, SCC and TC), little high-grade metamorphism (e.g. ganulite-facies metamorphism) and associated anatexis have been recognized in the Oulongbuluke Block (Zhang et al., 2001; Chen et al., 2009), which has limited our understanding of the tectonic evolution of the Oulongbuluke Block and its relationship with the NCC and TC and even Columbia supercontinent.

The objectives of this contribution are (1) to present new petrological, geochronological and geochemical data of 1.93–1.92 Ga metamorphism and anatexis in the Oulongbuluke Block, (2) to provide insights into the nature and extent of the 1.93–1.92 Ga tectonothermal event, and (3) to constrain the relationship of the Oulongbuluke Block to the Columbia supercontinent.

## 2. Geological background

The Oulongbuluke Block is located on the northeastern margin of the Qinghai-Tibet plateau, and is bounded to the south by the early Paleozoic North Qaidam HP-UHP metamorphic belt and to the north by the Qilian Block (Fig. 1). The Precambrian metamorphic basement of the Oulongbuluke Block is composed of the Delingha Complex, Dakendaban Group and Wandonggou Group (Fig. 2), which are in tectonic contact (Lu, 2002). The Delingha complex mainly consists of Paleoproterozoic granitic gneiss and enclosing amphibolite and granulite (Lu, 2002). Abundant zircon U-Pb age data suggest that these granitic gneisses formed between 2.47 Ga and 2.35 (Lu, 2002; Lu et al., 2008; Gong et al., 2012). A previous ID-TIMS zircon U-Pb investigation yielded an age of 2412 ± 14 Ma for the amphibolite enclaves (Lu, 2002). The Dakendaban Group can be divided into lower and upper sub-groups. The lower Dakendaban sub-group is located in the northern part of Wulan and Delingha and is composed of a set of high amphibolite-facies volcano-sedimentary rocks (Chen et al., 2012), whereas the upper sub-group is mainly exposed in the Delingha region and comprises supracrustal rocks similar to the khondalites (Chen et al., 2012). The Wandonggou Group is composed of greenschist-facies metasedimentary rocks and minor mafic metavolcanic rocks with metamorphic age of 1022 ± 64 Ma (Yu et al., 1994). In the late Paleoproterozoic, the metamorphosed crystalline basement of both the Delingha Complex and Dakendaban Group underwent medium-P/T type amphibolite-facies metamorphism at 1.95–1.91 Ga (Wang, 2009; Chen et al., 2013), followed by low-P/T type amphibolite-facies metamorphism at 1.85–1.83 Ga and medium P/T type amphibolite-facies metamorphism at 1.82–1.80 Ga (Chen et al., 2013). The late Palaeoproterozoic magmatism includes the presence of 1.85–1.82 Ga mafic dikes (Lu et al., 2008; Liao et al., 2014) and 1.80–1.76 Ga rapakivi granites (Lu et al., 2006; Chen et al., 2013).

## 3. Field relationships and microscopic textures

### 3.1. Field relationships

More than 50 samples of mafic granulites and migmatites were collected from the western and eastern segments of the Oulongbuluke Block adjacent to Delingha city and Wulan County. One mafic granulite and four migmatites samples were selected for U-Pb dating. The mineral abbreviations are based on Kretz (1983).

The mafic granulites primarily occur as veins, dikes or boudins in felsic gneiss and are locally interlayered with the felsic gneiss (Fig. 3a). The mafic granulites are parallel to the regional amphibolite-facies foliation. The sharp contact between the mafic granulite and host felsic gneiss can be easily distinguished. The mafic granulites, adjacent to the felsic gneiss, were mostly retrogressed to amphibolites. A dike swarm of amphibolite that intrude the felsic gneiss was also exposed in the Oulongbuluke Block (Fig. 3b). The felsic gneiss, which is the country rock of the mafic granulite and amphibolite, is gray, medium- to coarse-grained, and displays a homogenous granoblastic texture with a gneissic structure (Fig. 3a and b).

Outcrops of orthogneiss and paragneiss throughout this region and local metabasite (amphibolite) preserve features that are diagnostic of anatexis and locally display strong migmatization (Figs. 3 and 4). Anatexis is a general term for partial melting of the continental crust without specific reference to the degree of partial melting. Migmatite is a metamorphic rock that formed by partial melting. The melanosome is the darker part of the neosome in a migmatite that is rich in dark minerals such as biotite, garnet, cordierite, pyroxene and hornblende, whereas the leucosome is the lighter part of the neosome that consists dominantly of feldspar and quartz (Sawyer, 2008). The migmatitic gneiss in this study comprises a mixture of pale plagioclase-rich quartzofeldspathic leucosomes, which represent the former sites of melt segregation and/or accumulation, and a dark melanosome that represents the residuum from which melt was extracted. The residuum may be darker due to a higher concentration of mafic minerals (predominantly biotite and amphibole), although it is commonly intermediate to leucocratic in color. The plagioclase-rich (Pl-rich) leucosomes generally occur as innumerable thin layers in the felsic gneiss and are mainly composed of leucocratic plagioclase and quartz with very minor biotite, K-feldspar, titanite, apatite, and zircon. The proportion of thin leucosomes varies greatly from outcrop to outcrop, and the leucosomes range in thickness from millimeters to decimeters (Fig. 3c and d). The Pl-rich leucosomes are generally aligned subparallel to the foliation (Figs. 3c, d and 4a, c). The light-colored Pl-rich leucosomes are commonly coarser-grained than their host residuum. The Pl-rich leucosomes that contain quartz + plagioclase ± K-feldspar surround crystals of pink garnet, which represent peritectic phases (Fig. 4b). Kfs-rich pegmatite veins are often emplaced along the compositional layers (Figs. 3d and 4d) or crosscut them. The Kfs-rich pegmatite veins are centrimeters to decimeters in thickness. Some of them occur as veins that crosscut the melanosome and leucosome layers, whereas others are parallel to the foliation of the melanosome and leucosome layers (Figs. 3d and 4d). The pegmatite veins are flesh-colored due to their high content of K-feldspar porphyroclasts.