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Possible southwestward extrusion of the Ordos Block in the Late Paleoproterozoic: Constraints from kinematic and geochronologic analysis of peripheral ductile shear zones

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ABSTRACT

The Paleoproterozoic is a pivotal period of the tectonic evolution of the North China Craton (NCC). Various models have been postulated by previous researchers through the study of petrology and metamorphism, but the lack of structural analyses has hampered further understanding of the tectonic evolution of the NCC. A series of well-exposed ductile shear zones developed on the northern, northwestern and eastern edges of the Ordos Block in the western part of the NCC. We carried out detailed field studies along with isotopic dating focused on the kinematics and geochronology of the ductile shear zones. On the north margin of the Ordos block, the Wulashan-Daqingshan ductile shear zone is characterized by an E-W trending shearing foliation that steeply dips 75–80° to the north or south, with subhorizontal stretching lineation plunging 10–15° toward the east or west and dextral strike-slip shearing kinematics. On the west margin of the Ordos block is the Zongbieli ductile shear zone with top-to-the-NW thrusting kinematics. On the east margin of the Ordos block is the Xueling ductile shear zone with top-to-the-SE thrusting accompanied by sinistral strike-slip shearing kinematics.

The ^{40}Ar–^{39}Ar ages of deformed minerals from mylonitic high-grade metamorphic rocks and LA-ICP-MS U-Pb dating results of zircons from syn-tectonic anatectic granites reflect that the ductile shear zones surrounding the Ordos block deformed between 1.85 and 1.81 Ga. The similar deformation ages indicate that the ductile shear zones might be genetically correlated. The geometry, kinematics and geochronology characteristics of the Wulashan-Daqingshan ductile shear zone on the north margin, the Zongbieli ductile shear zone on the west margin, and the Xueling ductile shear zone combined with the Zhujiafang sinistral ductile shear zone on the east margin defined the possible southwestward extrusion of the Ordos block in the late Paleoproterozoic, which might have resulted from the westward subduction-collision of the Eastern Block under the Western Block at approximately 1.85 Ga and which is correlated with the amalgamation of the Columbia supercontinent.

1. Introduction

The North China Craton (NCC) is one of the oldest cratonic blocks in the world (Zhao and Zhai, 2013; Diwu et al., 2013), and the Precambrian tectonic evolution and continental growth in the NCC have been discussed in a number of recent works (Wilde et al., 2002, 2004; Wilde and Zhao, 2005; Kröner et al., 2005; Kusky and Li, 2003; Kusky et al., 2007; Santosh et al., 2006, 2007a,b, 2008, 2009a,b,c, 2010; Wan et al., 2013a; Zhao et al., 1998, 2001, 2002a, 2003a, 2005, 2006, 2009; Zhai and Santosh, 2011; Hu et al., 2013; Li et al., 2005, 2006, 2010, 2011a,b, 2012; Li and Zhao, 2007; Wu et al., 2012, 2013). There is no consensus about its subdivision or the tectonic models for the formation and evolution of the craton (Zhao and Zhai, 2013).

Four main models have been described in terms of field-based metamorphic, geochemical, geophysical and geochronological

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studies: (1) Zhai (2011) proposed a two-stage cratonization model of the NCC. The first stage took place at the end of the Neoarchean at ~2.5 Ga, when several micro-blocks were amalgamated. The second cratonization event consisted of cratonic reworking corresponding to a rifting-subduction-collision at 2.3–1.97 Ga and subsequent extension-uplifting related to upwelling mantle at 1.97–1.82 Ga, which might be linked to the assembly and breaking up, respectively, of the Columbia Supercontinent. (2) Zhao et al. (2002a, 2005) proposed that three Paleoproterozoic orogenic belts existed in the NCC. The Khondalite Belt resulted from the amalgamation of the Yinshan and Ordos Blocks to form the Western Block at ~1.95 Ga, whereas the Trans-North China Orogen resulted from a collision of the Western and Eastern blocks above an eastward subduction zone at ~1.85 Ga. The Jiao-Liao-Ji Belt records opening and closing of an intra-continental rift within the Eastern Block in the period 2.2–1.9 Ga (Li et al., 2005, 2006, 2011a,b, 2012; Li and Zhao, 2007; Tam et al., 2012a,b; Wu et al., 2012, 2013). (3) Faure et al. (2007) and Trap et al. (2007, 2008, 2009a,b, 2011, 2012) postulated that an old continental block named the Fuping Block intervenes between the Eastern and Western (Ordos) Blocks, which were separated from the Fuping Block by the Zanhuang Ocean and the Lüliang Ocean, which closed at ~2.1 and 1.9–1.8 Ga, respectively, and both of which were subducted westward. (4) Kusky et al. (2007) proposed that the northern margin of the craton experienced a continental collision with part of the Columbia supercontinent (South America) at 1.93–1.92 Ga, followed by the development of an extensive craton-wide rift system at 1.85–1.80 Ga.

That the Paleoproterozic is a pivotal period for the tectonic evolution of the NCC can be inferred from the above models despite their differences. And almost all of the points were obtained from the analyses of three Paleoproterozoic linear structural belts developed in the North China Craton (Zhang et al., 1994, 2007, 2009; Faure et al., 2007; Trap et al., 2007, 2008, 2009a,b, 2011, 2012; Li et al., 2010, 2012). Among these, the "Khondalite Belt" (Zhao et al., 2002a, 2005), which is also known as the "Fengzhen Orogenic Belt" (Zhai and Peng, 2007; Zhai and Santosh, 2011) or the "Inner Mongolia Suture Zone" (part of the Khondalite Belt/Fengzhen Belt) (Santosh et al., 2010), and the "Trans-North China Orogen" (Zhao et al., 2002a, 2005), which is also known as the "Jinyu Orogenic Belt" (Zhai and Peng, 2007; Zhai and Santosh, 2011), are located on the north and east margins of the Ordos block, respectively (Fig. 1). Studies of its petrology and metamorphism have provided abundant information about the evolution of the NCC, whereas few investigations on the structural deformation of the NCC have been conducted (Trap et al., 2007, 2008, 2009a,b, 2011, 2012; Zhang et al., 2007). The lack of structural data has further hampered understanding of the Precambrian evolution of the NCC.

Ductile shear zones consisting of strike-slip ductile shear zones, large-scale thrusting and folding, and transcurrent tectonics are extensively exposed in the Paleoproterozoic linear structural belts of the NCC (Yu and Sun, 1996; Liu et al., 2007; Chen et al., 2008; Trap et al., 2007, 2008, 2009a,b, 2011, 2012; Zhang et al., 2007), which may provide important information about the crustal structure and the regional structure (Isik, 2009).

In this paper, we report detailed field studies focused on the geometry and kinematics along with LA-ICP-MS U–Pb analyses of zircon and $^{40}Ar/^{39}Ar$ dating of deformed minerals in three ductile shear zones: the Wulashan-Daqingshan ductile shear zone, the Zongbieli ductile shear zone and the Xueling ductile shear zone located on the northern, the northwestern and the eastern margins of the Ordos Block, respectively (Fig. 1). The geometry, kinematics and geochronology characteristics of the ductile shear zones defined the possible southwestward extrusion of the Ordos block, indicating that the North China Craton underwent a complicated structural process during the late Paleoproterozoic.

2. Wulashan-Daqingshan strike-slip ductile shear zone

2.1. General geological features

2.1.1. Main stratigraphic unit

The Wulashan-Daqingshan area is located on the north margin of the Ordos block in the central part of the EW-trending Khondalite Belt (Fig. 1). The Precambrian basement was originally divided into the Sanggan Group, the Wulashan Group and metamorphosed magmatic units (Fig. 2) (Yang et al., 2003). The metamorphosed magmatic units include garnet granite, augen granitic gneiss, charnockite and tonalite-granodiorite gneiss. The Sanggan Group is composed mainly of granulite facies supracrustal rocks of Late Neoarchean age (Ma et al., 2012) (Fig. 3). Granulite series are composed of various granulites, pyroxene plagioclase gneiss and magnetite quartzite, and the primary rocks are a sequence of mafic-felsic volcanic and sedimentary rocks (Liu et al., 2007). The Wulashan Group was divided into the Upper and Lower Wulashan Subgroups (Fig. 3), of which the lower subgroup, a meta-volcano-sedimentary association, was considered to have formed during the Archean (Yang et al., 2003). The Upper Wulashan Subgroup is composed of the "Khondalite Series" including metamorphosed clastic sediments, calc-silicate rocks, marbles, garnet-biotite gneiss and some basic igneous rocks (Dong et al., 2013a,b), which represent passive continental margin metasediments (Condie et al., 1992). The garnet-biotite gneiss unit was named as the Daqingshan Supracrustal rocks by Dong et al. (2013a). Recent SHRIMP and LA-ICP-MS U–Pb zircon ages revealed that the sedimentary protoliths of the Khondalite Series were deposited in the period of 2.3–1.95 Ga and experienced high-grade granulite facies (HT-HP and HT-UHT) metamorphism at 1.97–1.82 Ga (Dong et al., 2012, 2013a,b; Wan et al., 2006; Xia et al., 2006a,b, 2008, 2009; Yin et al., 2009, 2011; Li et al., 2011a,b; Guo et al., 2012; Santosh et al., 2007a,b, 2009a,b; Zhai and Santosh, 2011; Zhai, 2011).

2.1.2. Structural framework

The Wulashan-Daqingshan area mainly consists of the late Archean Wulashan group and Sanggan group high-grade metamorphic rocks and late Paleozoic granites. A series of parallel ductile shear zones developed along the trend of the orogen and anatectic granite veins were emplaced along the regional gneissic and shearing foliation, which compose the main architecture of the Wulashan-Daqingshan area. Field investigations indicate that the ductile shear zones are mainly distributed along the contacts of different tectonic units or within the late Archean Wulashan group and Sanggan group metamorphic complex. The widths of the E-W trending ductile shear zones vary from decameters to kilometers. In the central part of Wulashan, both the anatectic granite veins and the ductile shear zone are cut by late Carboniferous granites. The largest Dahuabei pluton intruded at 353 ± 7 Ma (Miao et al., 2001). To the east, the ductile shear zone is covered by the Jurassic basin and was disturbed by late Mesozoic thrusting (Fig. 2).

2.2. Syn-tectonic anatectic granite veins

The western part of Wulashan has numerous anatectic plutons consisting of gneissic anatectic biotite monzonitic granites, K-feldspar granites and gneissic quartz diorites which intruded along the gneissic foliation of the Wulashan group gneiss. The geometry of the anatectic plutons is different from the late Paleozoic Dahuabei pluton. The anatectic plutons have a strip geometry and are 10–25 km long and 1–2 km wide with a length:breadth ratio of approximately 10:1 (Fig. 2). The narrow strips of anatectic granite veins developed along the gneissic foliation at outcrop scales (Fig. 4).