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Protolith reconstruction and geochemical study on the wall rocks of Anshan BIFs, Northeast China: Implications for the provenance and tectonic setting

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ABSTRACT

The petrography, as well as major and trace element (including rare earth element) compositions of plagioclase amphibolites and schists from the Anshan Group in the Qidashan and Gongchangling iron deposits, the western Liaoning Province, have been investigated to determine protolith nature, provenance and tectonic setting. The geochemical analysis has revealed that protoliths of the plagioclase amphibolite and schist could be basic volcanic rock and mudstone/siltstone, respectively. Based on the results of protolith reconstruction, metapelites (namely, the schists) have been used to evaluate their provenance and weathering history. The metapelites can be divided into two groups based on the Chemical Index of Alteration (CIA) and Plagioclase Index of Alteration (PIA) values, but both groups were sourced from an active tectonic setting. Zr/Sc and Th/Sc ratios illustrate that the metapelites, which display no significant sediment recycling, might be the first-cycle erosion products. Various discrimination diagrams for sedimentary provenance show that the metapelites predominantly derived from the mixed felsic and basic sources. The geochemical characteristics and discrimination diagrams of plagioclase amphibolites and schists demonstrate that the Qidashan and Gongchangling iron deposits might be formed in an Archean active tectonic setting related to subduction of an oceanic slab.

1. Introduction

Iron ores derived from banded iron formations (BIFs) rank among the largest ore deposits and are the principal source of iron for the global steel industry (Bekker et al., 2010). BIFs occur in the Precambrian geologic record over a wide time span. The age of BIFs ranges from 3.8 Ga to 1.8 Ga, reappearing at the end of the Neoproterozoic Era (ca. 0.8–0.6 Ga), and the peak in BIF abundance is ca. 2.5 Ga (Huston and Logan, 2004; Klein, 2005). BIFs can be divided into the Algoma-type associated with volcanic rocks, and the Superior-type stratabound in sedimentary sequences (Gross, 1965). Although many aspects of their origin remain unsolved, it is widely accepted that the deposition of BIFs has been genetically linked to geological events, including the Great Oxidation Event (Bekker et al., 2004; Chen et al., 1991, 1994, 1996; Cloud, 1973; Huston and Logan, 2004; Tang and Chen, 2013; Tang et al., 2013a, b; Zhao, 2010), mantle plume activity (Abbott and Isley, 2001; Bekker et al., 2010; Isley, 1995; Isley and Abbott, 1999), Snowball Earth Event (Klein, 2005), and impact event (Glikson and Vickers, 2007; Slack and Cannon, 2009; Young, 2013). The study of BIFs is of great use in understanding the early history of the Earth and obtaining the information on the chemical compositions of coeval atmosphere and hydrosphere (Bekker et al., 2010; Chen, 1990; Chen and Zhao, 1997; Klein, 2005).

In China, BIFs are mainly distributed in the North China Craton (NCC), including the western Liaoning, the eastern Hebei, the southwestern Henan, the western Shandong and the northern Shanxi Provinces, with the western Liaoning area being the most important iron ore province (Xie et al., 2009; Zhang et al., 2012b). The BIFs in China show certain characteristics: (1) Algoma-type BIFs are major, while Superior-type BIFs are minor; (2) oxide facies BIFs are predominant, while silicate, carbonate and sulfide facies are rare; (3) most of the iron ores are low-grade (average of ~30% Fe-content); and (4) BIFs usually suffered varying degrees of metamorphism (from subgreenschist to granulite facies) and intense deformation (Zhai and Windley, 1990; Zhang, 2009; Zhang et al., 2012b). Although a lot of studies concerning the NCC with respect to regional geology, petrology, geochemistry and geochronology have been done, the tectonic setting of BIFs in the NCC remains obscure because of the multiple deformation and metamorphic processes.

Geochemical features of volcanic rocks are widely used to discriminate tectonic setting. Geochemical studies of clastic sedimentary rocks also provide information regarding source rock composition, paleo-weathering conditions and tectonic setting (Bhatia, 1985; Bhatia and Taylor, 1981; Roser and Korsch, 1986). Trace elements, in particular the rare earth elements (REE) and high field strength elements (HFSE), which are relatively low in mobility during weathering, hydraulic sorting, diagenesis and metamorphism, are useful for

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provenance and tectonic setting studies (Bhatia, 1985; McLennan and Taylor, 1980; Taylor and McLennan, 1985).

The Qidashan and Gongchangling iron deposits are typical BIFs in the western Liaoning Province. In this paper we use the major and trace element (including REE) composition to confirm the protolith nature. We also discuss the ancient tectonic setting based on the geochemical characteristics of plagioclase amphibolites and metamorphic clastic sedimentary rocks.

2. Regional and local geology

The NCC is one of the oldest cratons in the world, preserving ca. 3.8 Ga rocks in the western Liaoning Province, and it has experienced a prolonged geological history (Liu et al., 1992). The tectonic division of basement in the NCC is controversial. According to Zhai and co-workers (Zhai and Santosh, 2011; Zhai et al., 2000), at least seven micro-blocks can be identified including the Jiaoliao Block, Qianhuai Block, Ordos Block, Jinning Block, Xuchang Block, Xuhuai Block and Alashan Block. Zhai and Santosh (2011) proposed that the Precambrian crustal evolution of the NCC was related to three major geological events: (1) a major phase of continental growth at ca. 2.7 Ga; (2) the amalgamation of micro-blocks and cratonization at ca. 2.5 Ga; and (3) Paleoproterozoic rifting–subduction–accretion–collision tectonics and subsequent high-grade granulite facies metamorphism–granitoid magmatism during ca. 2.0–1.82 Ga. However, Zhao et al. (2001, 2003, 2005) proposed that the basement of the NCC can be divided into the Eastern and Western Blocks, separated by the intervening Central Zone (Trans-North China Orogen). The Western Block can be further subdivided into the Ordos Block in the south and the Yinshan Block in the north along the east–west-trending Khondalite Belt, and the amalgamation of these two blocks occurred sometime before the collision of the Western and Eastern Blocks, while the Eastern Block underwent the Paleoproterozoic rifting along its eastern continental margin and the final closure of this rift system at ca. 1.9 Ga led to the formation of the Jiao-Liao-Ji Belt (Zhao et al., 2005).

The Anshan area is located in the north part of the Eastern Block and contains the early Precambrian Anshan Group and Liaohe Group (Fig. 1; Zhai and Windley, 1990; Zhao et al., 2003). An unconformity separates the underlying Archean Anshan Group, which contains the abundant BIFs, from the overlying Paleoproterozoic Liaohe Group. Both the Anshan and Liaohe Groups are overlain unconformably by undeformed sediments (Tang et al., 2011, 2013a; Zhai and Windley, 1990; Zhai et al., 1990; Zhou, 1986).

The Anshan basement can be divided into three parts: the Tiejiashan gneiss, the Anshan gneiss and the Anshan supracrustal rocks (Zhai et al., 1990). The Tiejiashan gneiss occurs at the Tiejiashan area, on the east of Anshan City, forming the basement of the Anshan supracrustal rocks. The Anshan gneiss intrudes the Anshan supracrustal rocks and their intercalated BIFs, resulting in the latter being observed as variable-sized enclaves in the former (Zhai and Windley, 1990). Rock types of the Anshan Group comprise plagioclase amphibolites, leptynites, schists, migmatites, BIFs and others including siliceous rocks and carbonates (Zhou, 1994).

The age of the BIFs in the Anshan area is constrained by various methods. Because Zhong (1984) obtained a Rb–Sr isochron age of 2829 ± 62 Ma and a 2862 ± 51 Ma, and Song et al. (1996) reported a zircon U–Pb age of 2962 ± 4 Ma and a 2964 ± 6 Ma for the Tiejiashan gneiss, and a zircon U–Pb age of 2475 Ma for the Qidashan granitic gneiss (the Anshan gneiss), it has been roughly deduced that the age of the Anshan supracrustal rocks must be between 2500 Ma and 2900 Ma according to their tectonic relationship. Since plagioclase amphibolites are generally closely related to the BIFs, the age of the protolith of plagioclase amphibolites must closely represent the age of the BIFs (Zhang et al., 2011). Qiao et al. (1990) reported the Sm–Nd

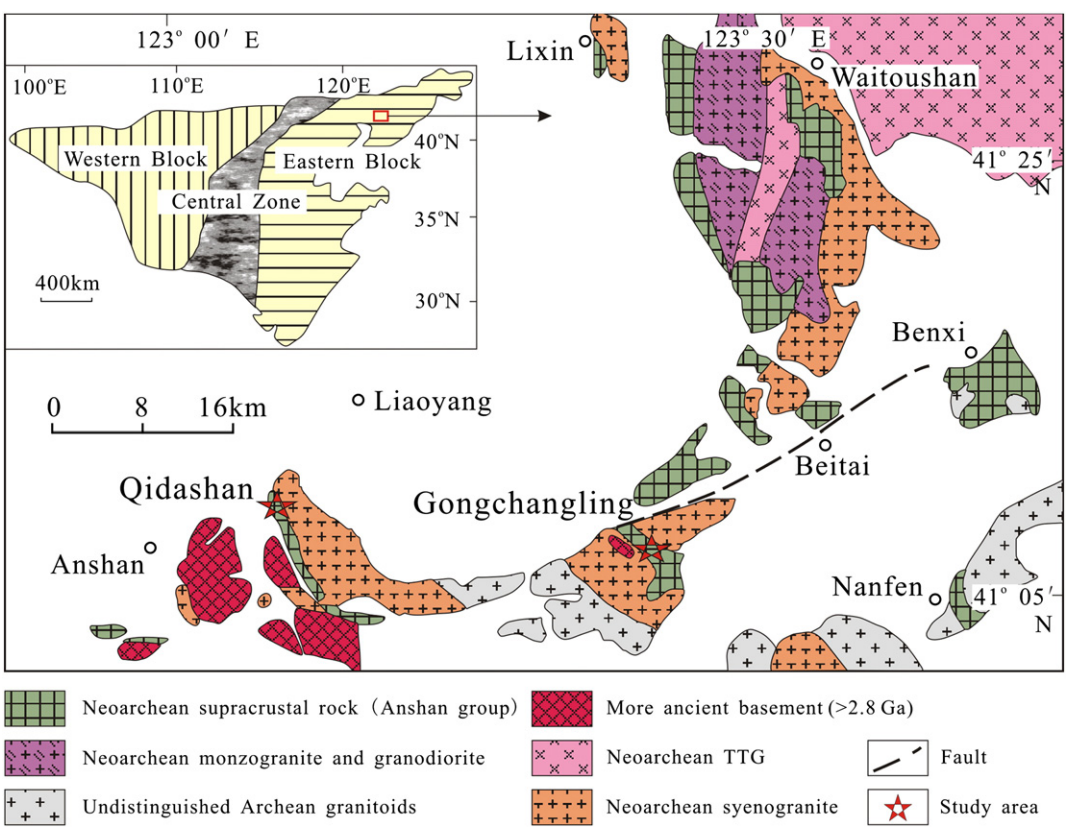

Fig. 1. Geological map of the Anshan–Benxi area, Liaoning Province.
Modified after Wan (1993) and Zhao et al. (2003).