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# Petrological and geochemical features of the Jingtieshan banded iron formation (BIF): A unique type of BIF from the Northern Qilian Orogenic Belt, NW China

Xiu-Qing Yang [a,b], Zuo-Heng Zhang [c,*], Shi-Gang Duan [b], Xin-Min Zhao [d]

[a] School of Earth and Space Sciences, Peking University, Beijing 100871, China
[b] MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
[c] Chinese Academy of Geological Sciences, Beijing 100037, China
[d] Xi'an Center of China Geological Survey, Xi'an 710054, China

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ABSTRACT

The Jingtieshan banded iron formation (BIF) is located in the Northern Qilian Orogenic Belt (NQOB) in NW China. The BIFs are hosted in Mesoproterozoic Jingtieshan Group, a dominantly clastic-carbonate sedimentary formation, and was metamorphosed to lower greenschist facies. The Jingtieshan BIFs include oxide-, carbonate- and mixed carbonate–oxide facies, and consist of alternating iron-rich and silica-rich bands. The BIFs are composed essentially of specularite and jasper, with minor carbonate minerals and barite. The $SiO_2 + Fe_2O_3$ content is markedly high in the oxide facies BIF, followed by FeO, $CO_2$ and Ba, with the other elements usually lower than 1%, suggesting that the original chemical sediments were composed of Fe, Si, $CO_3^{2-}$ and Ba. The positive correlation between $Al_2O_3$, $TiO_2$ and Zr in the BIFs indicates that these chemical sediments incorporate minor detrital components. Oxide facies BIF shows low HFSE, low $\sum$REE and low Y/Ho. The Post Archean Australian Shale-normalized REE patterns for Jingtieshan BIFs are characterized slight LREE depletion, strong positive Eu anomalies and lack of significant negative Ce anomalies. Siderite in the carbonate- and mixed carbonate–oxide facies BIF shows negative $\delta^{13}C$ values varying from −8.4‰ to −3.0‰, and $\delta^{18}O$ values show a range of −16.6‰ to −11.7‰. The geochemical signatures and carbon–oxygen isotopes suggest origin from high-temperature hydrothermal fluids with weak seawater signature for the sediments of Jingtieshan BIFs. The absence of negative Ce anomalies and the high $Fe^{3+}/\sum Fe$ ratios of the oxide facies BIF do not support ocean anoxia. In contrast to the three main types (Algoma-, Superior- and Rapitan-type) of global BIFs, the Jingtieshan BIFs represent a unique type with features similar to those of sedimentary-exhalative mineralization.


## 1. Introduction

Precambrian banded iron formations (BIFs) are considered as chemical sediments, typically thin bedded or laminated, with anomalously high content of iron as the major chemical characteristic, and commonly but not necessarily containing layers of chert (James, 1954). The earliest Precambrian BIFs were deposited at 3.8 Ga, and the Neoarchean and Early Proterozoic witnessed major BIF deposition (James, 1983; Trendall, 2002). At 1.85 Ga, large-scale BIF formation was terminated because of a major change in ocean chemistry (Holland, 1984; Poulton et al., 2010). The apparent sudden reappearance of BIFs after 1 Ga hiatus in the sedimentary record has been considered as a geologically unique feature of the Neoproterozoic (Holland, 2005; Bekker et al., 2010; Cox et al., 2013). Large BIF deposits are absent during this age gap (1.85–1.0 Ga), but several small BIF and iron rich lithologic units in sedimentary rock dominated successions are also known. Some of the examples of anomalous and small deposits include the Sherwin Formation and the Munyi Member of the Corcoran Formation in northern Australia (Abbott and Sweet, 2000), and some of the BIFs related to VMS deposits belonging to Mesoproterozoic (e.g., Slack et al., 2007; Bekker et al., 2010).

The Archean and Paleoproterozoic BIFs have been classified into Algoma-type and Superior-type (Gross, 1965; Gross and McLeod, 1980). The Neoproterozoic BIFs are mainly Rapitan-type (Button et al., 1982; James, 1992). The origins of Archean and Paleoproterozoic BIFs including those in the North China Craton have been well studied (e.g., Zhai and Santosh, 2013). However,

* Corresponding author. Tel.: +86 1068999622.
*E-mail addresses:* xiuqing2008@126.com (X.-Q. Yang), zuoheng@hotmail.com (Z.-H. Zhang).

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Meso–Neoproterozoic BIFs are distinctly different from the extensively documented Archean and Paleoproterozoic counterparts. For example, with some exceptions, the compositional bands are generally poorly developed or entirely absent in some BIFs, and the banding consists of hematite and jasper layers. Neoproterozoic BIFs more commonly occur as ferruginous laminated siltstone or within the matrix of diamictite. The Archean and Paleoproterozoic BIFs usually display different grades of metamorphism, and are dominated by magnetite. In contrast, the Meso–Neoproterozoic BIFs are unmetamorphosed or were subjected to low grade metamorphism, with hematite as the dominant mineral. The ultimate source of the iron and process of oxidation from $Fe^{2+}$ to $Fe^{3+}$ in the Meso–Neoproterozoic occurrences are unclear (Bekker et al., 2010; Cox et al., 2013). BIFs are not only important sources of iron ore for industry but have also been central to research studies related to the evolution of life, oceans, and the atmosphere in the Archean and Proterozoic (Lascelles, 2007; Poulton et al., 2010; Bekker et al., 2010; Young, 2013).

The Jingtieshan BIFs are wellknown deposits in the Northern Qilian Orogenic Belt (NQOB), in the western Gansu Province of China. Proven iron ore reserves of the whole deposit are 557 million tons, with the average Total Fe grade of 40% (Li et al., 2012a; Li et al., 2014). Besides iron, the Jingtieshan deposit also contains considerable amounts of barium and copper. The BIFs are mainly hosted within clastic-carbonate sedimentary formation of the Meso–Neoproterozoic Jingtieshan Group, and recent studies confirm Mesoproterozoic (Zhang et al., 2001, 2014; Mao et al., 2003). The rocks in the Jingtieshan Group were metamorphosed to lower greenschist facies (Yang et al., 1991; Sun et al., 1998). The Jingtieshan BIFs share many characteristics of Neoproterozoic BIFs, and are characterized by specularite, jasper, barite, and high contents of $SiO_2$, $Fe_2O_3$ and Ba. Although several studies have been carried out on the Jingtieshan BIFs (e.g., Yang et al., 1991; Xue et al., 1997; Sun et al., 1998; Liu et al., 1998; Zhou and Yue, 1999; Mao et al., 2003), their primary depositional conditions, genesis and the genetic types remain unclear. Some workers have correlated these BIFs with Sedex-type iron deposit (Xue et al., 1997; Liu et al., 1998; Zhou and Yue, 1999; Mao et al., 2003) or Superior-type BIFs (Sun et al., 1998). In this paper, we present new petrologic, geochemical and carbon–oxygen isotopic data from the Jingtieshan BIFs, with a view to understand their formation as well as correlation with similar deposits elsewhere in the world.

## 2. Geologic setting

The NNW-trending NQOB of NW China is located at the central part of the Qinling-Qilian-Kunlun composite orogenic belt, and lies between the North China Craton, Tarim Craton and Central Qianlian Blocks (Fig. 1) (Song et al., 2013; Huang et al., 2014). The Precambrian geological evolutionary history of NQOB can be summarized as follows: (1) The Paleoproterozoic Beidahe Group was deposited in rift-related geosyncline and is represented by upper greenschist to lower amphibolites facies metamorphic rocks, composed of biotite-plagioclase gneiss, quartz schist and dolomitic marble. (2) Early Mesoproterozoic Zhulongguan Group developed in the arc- back-arc basin, and is represented by metabasalt and metasedimentary units including marble and minor BIF. (3) Mesoproterozoic Jingtieshan Group with thickness of 4000 m formed in residual ocean basin. The formation age of the Jingtieshan Group has not been precisely constrained. Yang et al. (1991) reported Rb–Sr isochron ages from phyllite as 586–670 Ma. Sm–Nd isotope data on BIFs yielded ages around 1309 Ma (Yang and Zhao, 1999). Recent studies confirm the Jingtieshan Group as Mesoproterozoic in age, based on stratigraphic correlation and the new dating results. Mao et al. (2003) argued that the Jingtieshan Group distributed between the underlying Early Mesoproterozoic Zhulongguan Group and overlying Daliugou Group of Qingbaikou System. Our recent zircon LA–MC–ICP-MS dating results also indicate that Jingtieshan Group formed at ~1.3 Ga (our unpublished data). The group can be divided into the lower succession and the upper succession. The BIF-bearing lower succession is mainly composed of clastic rocks locally interlayered with dolomitic marble. The upper succession is a thick sequence of marble. (4) Neoproterozoic Daliugou Group composed of marble with clastic rocks deposited in a stable shallow sea, unconformable overlying the Jingtieshan Group. (5) The Late Neoproterozoic Baiyanggou group deposited in a rift basin, and is composed of thick conglomerate with intermediate-basic volcanic rocks at some places. The Phanerozoic strata mainly

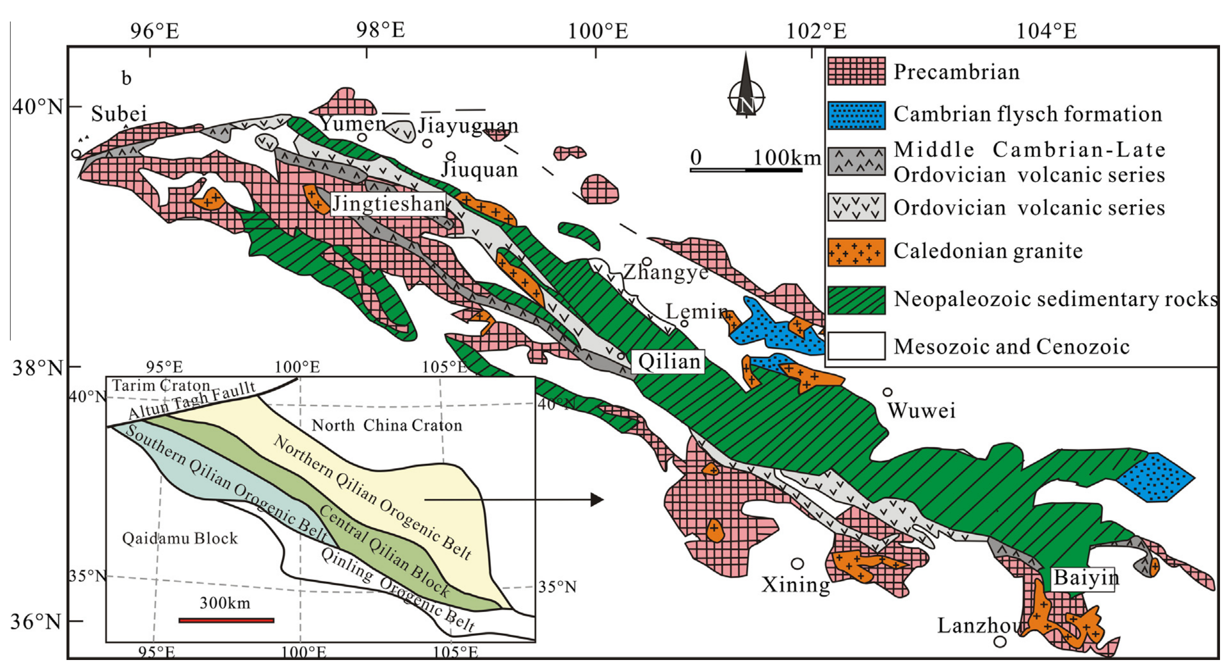


**Fig. 1.** Geological map of the Northern Qilian area, China (modified from Li et al. (2005)).