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Types and general characteristics of the BIF-related iron deposits in China

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ABSTRACT

BIFs (banded iron formations) in China, which account for approximately 64% of the total identified resources in the country, belong to two categories: a predominant Neoarchean Algoma-type and a few Paleoproterozoic Superior-type. A minor group of BIFs developed in the Neoproterozoic is also representing, having possible correlation with the "Snowball Earth" scenario. Spatially, the BIFs in China are mainly distributed in the North China Craton. They experienced intense metamorphism and deformation, which led to the majority of iron oxides changing into coarse-grained magnetites. Though their ores generally contain only 30% TFe, the BIFs are potential targets of industrial exploitation by magnetic beneficiation. On the basis of ore-forming age, host formations, mineral assemblages, and grade of the ores, the BIF-related iron deposits in China are classified into seven types. (1) Anshan-type: Neoarchean volcanic sedimentary formations with magnetite as the main ore mineral (20% ≤ TFe < 50%); this group belongs to the Algoma-type, and is represented by the Waitoushan iron deposit in Liaoning province. (2) Yuanjiacun-type: Paleoproterozoic clastic sedimentary formation with magnetite, martite and some siderite (20% ≤ TFe < 50%) as the major ore minerals; this group belongs to the Superior-type, and is represented by the Yuanjiacun iron deposit in Shanxi province. (3) Dalizi-type: Paleoproterozoic clasolite–carbonate formation, with magnetite, hematite and siderite as the useful minerals (20% ≤ TFe < 50%); this group belongs to the Superior-type, and is represented by the Dalizi iron deposit in Jilin province. (4) Jingtieshan-type: Mesoproterozoic BIFs with hematite and specularite as the ore minerals (20% ≤ TFe < 50%); this group belongs to Superior-type, and is represented by the Jingtieshan iron deposit in Gansu province. (5) Xinyu-type: Neoproterozoic banded iron formations (BIFs) with magnetite as the dominant ore mineral (20% ≤ TFe < 50%); this group belongs to the Rapitan-type, and is represented by the Yangjiaqiao iron deposit in Jiangxi province. (6) Gongchangling-type: high-grade iron deposits developed from the Anshan-type iron deposits by late hydrothermal superimposition and reformation. The ores are mainly composed of magnetite, with TFe grade higher than 50%, and represented by mining area II of Gongchangling iron deposit in Liaoning province. (7) Shilu-type: Neoproterozoic high-grade iron deposit, mainly hematite, with TFe grade greater than 50%, represented by the Shilu iron deposit in Hainan province.

1. Introduction

The Precambrian banded iron formations (BIFs), belonging to marine sedimentary rocks, are mainly composed of iron oxides and gangue minerals. The TFe content generally ranges from 20% to 40% with extremely low content of Al_2O_3 (James, 1954). Cross (1980) divided the Precambrian BIFs into Algoma-type and Superior-type (or Hamersley-type), based on their difference in depositional environments and symbiotic rock associations. The Algoma-type BIFs are of relatively small scale, usually associated with synchronous volcanic rock assemblage and accompanied by pyroclastic rocks in the middle–upper part of greenstone belts (Goodwin, 1962), such as BIFs in the greenstone belts of Abitibi in Canada, Yilgarn in Australia and Dharwar in southern India. The Superior-type BIFs are of relatively large scale, which are mostly related to sedimentary formations, with no synchronous volcanic assemblages, and deposited in transgressive sequences on shallow continental shelves. Most of the BIFs were developed in the Neoarchean and Paleoproterozoic periods (3.0–1.8 Ga), whereas the Superior-type BIFs were formed in Paleoproterozoic period (2.5–1.8 Ga). Examples include the Hamersley in Australia, Quadrilatero Ferrifero in Brazil, Lake Superior in North America, Kursk in Russia, Krivoy Rog in Ukraine and Transvaal in South Africa. In addition, a minor category of Rapitan-type BIFs, which formed in the Neoproterozoic period has also been reported, and correlated to the "Snowball Earth" event, such as the Rapitan in Canada, Urucum in Brazil and Damara in South Africa (Klein, 2005). The BIF-related iron ore deposits constitute one of the important iron resources, with the quantity of both exploitation and resource reserve ranking as the first in the world. The ores are mainly hematite, with TFe content more than 50%.

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In China, the BIF-related iron deposits are the most important type of iron deposits, accounting for approximately 64% of the total identified resources. However, most of them are low-grade iron ores (in China, the low-grade iron ore is defined as 20% ≤ TFe < 50%, and the iron ore with TFe ≥ 50% is defined as high-grade iron ore). The high-grade iron ores only account for less than 2%, which is significantly different from other countries where the high-grade ores are mainly BIF type iron ores. In terms of metallogenic characteristics, the BIFs in China are different from most of the other BIFs in the world. Most of the BIFs in China belonging to Algoma-type were deposited at ca. 2.5 Ga and were strongly metamorphosed (Dai et al., 2012; Shen et al., 2005, 2011; Song et al., 1992; Wan et al., 2012; Wang and Zang, 1995; Zhai and Santosh, 2011, 2013; Zhai and Windley, 1990; Zhai et al., 1990; Zhang et al., 2011, 2012a; Zhou, 1987). A few BIFs belong to Superior-type, such as the Yuanjiacun iron deposit in Shanxi province (Cheng, 1957; Shen, 2012; Shen et al., 2005, 2011; Zhai and Windley, 1990; Zhu et al., 1988), the Dalizi iron deposit in Jilin province (Chen et al., 2010; Li et al., 2012a, 2012b) and the Jingtieshan iron deposit in Gansu province (Sun et al., 1998). The BIF-related iron deposits in Jiangnan Paleocontinent, such as the Yangjiaqiao and Liangshan iron deposits are Rapitan-type (Tang et al., 1987; Yu et al., 1989). The Shilu iron deposit in Hainan province and the Gongchangling iron deposit in Liaoning province are BIF-related high-grade iron deposits (Cheng, 1957; Shen, 2012; Xu et al., 2013; Zhai and Windley, 1990). On the basis of characteristics of rock formations, Cheng (1957) divided the BIF-related iron deposits into three types as follows: 1) Those associated with quartz–plagioclase-amphibolite and also striped hornblende-bearing rocks of the Durcha type of Scotland. 2) Pelitic or argillaceous type, with the ore containing intercalations of and embedded in phyllite or fine chlorite or mica-schist. 3) Psammitic or siliceous type, with the ore occurring in quartz–feldspar-gneiss or quartzite. Cheng (1957) also proposed that the high-grade iron ores might be formed by four processes: 1) compact and massive magnetite and/or hematite (including specularite and martite) formed by hydrothermal replacement of the banded ore; 2) porous magnetite or hematite (mainly specularite) formed by the hydrothermal leaching of silica and with relative enrichment in iron in the banded ore; 3) compact and massive magnetite or hematite formed by the same process as the banded ore; 4) porous hematite, limonite and goethite formed chiefly by leaching of silica of the banded ore by meteoric waters. Shen et al. (2005) divided the Precambrian iron deposits into 5 types: (volcanic) meta-sedimentary type, volcanic type, sedimentary type, complex type and magmatic type. Among these, the (volcanic) meta-sedimentary type and the complex type are BIF-related. However, none of the above provides a comprehensive classification. For example, the Rapitan-type of the Yangjiaqiao and Liangshan iron deposits in Xinyu area of Jiangxi province are not included in all these classifications. Also, most of the studies were published in Chinese journals, and are not available to the international audience. In this overview, we attempt to provide a systematic summary of the major characteristics such as ore-forming age, ore-bearing formations, mineral assemblages, and grade of the ores of 7 types of the BIF-related iron deposits in China, namely Anshan-type, Yuanjiacun-type, Dalizi-type, Jingtieshan-type, Xinyu-type, Gongchangling-type and Shilu-type.

2. Distribution of BIF-related iron deposits in China

BIFs in China were mainly formed between 2500 Ma and 2550 Ma (Dai et al., 2012; Wan et al., 2012; Wang and Zang, 1995; Zhang et al., 2011, 2012b). Most of them belong to the Algoma-type, with a small number of BIFs formed in the Paleoproterozoic (e.g. Yuanjiacun-type iron deposits and Dalizi-type iron deposits), the Mesoproterozoic (e.g. Jingtieshan-type iron deposits) and the Neoproterozoic (e.g. Xinyu-type iron deposits and Shilu-type iron deposit) periods. Spatially, China's BIFs, correlated with greenstone belts, are mainly distributed in the North China Craton (Fig. 1). The BIF-related iron deposit clusters in the North China Craton include the Anshan-Benxi (in Liaoning province), Jidong (in Hebei province)–Miyun (in Beijing), Wutai (in Shanxi province), Wuyang (in Henan province), Huoqiu (in Anhui province) and Luxi (in Shandong province). The Paleoproterozoic Superior-type BIFs occur in the Lvliang mountains (Yuanjiacun-type iron deposits) and Liaoji rift (Dalizi-type iron deposits), the Mesoproterozoic Superior-type BIFs formed in the Qilian mountains (Jingtieshan-type iron deposits), and a few Neoproterozoic Rapitan-type BIFs were deposited at the southern margin of the Jiangnan Paleocontinent (Xinyu-type iron deposits). The Jingtieshan-type iron deposits were formed in the Mesoproterozoic marine basin in Qilian Mountain and Shilu-type iron deposits were formed in the Neoproterozoic marine basins of Hainan Island.

3. Types and general characteristics of the BIF-related iron deposits in China

The BIFs in China experienced intense metamorphism and deformation, which led to the majority of iron oxides transforming into coarse-grained magnetites. Though their ores generally contain only 30% TFe, the BIFs are favorable for industrial exploitation using magnetic beneficiation, and are therefore termed as sedimentary metamorphic type iron deposits. Based on the ore-forming age, ore-bearing formation, mineral assemblage, and grade of the ores, the BIF-related sedimentary metamorphic type iron deposits in China can be divided into seven types (Table 1): (1) Anshan-type: associated with Neoarchean volcanic sedimentary formation, with magnetite as the main ore mineral (20% ≤ TFe < 50%). These BIFs belong to Algoma-type, represented by the Waitoushan, Nanfen, Qidashan, Xi'anshan, Dagushan and Yanqianshan iron deposits in Liaoning province, Shuichang, Shirengou, Sijiaying, Macheng, Douzigou, Zhoutaizi, and Zhalanzhangzi iron deposits in Hebei province, Sanheming and Gongyiming iron deposits in Inner Mongolia, Shanyangping and Heishanzhuang iron deposits in Shanxi province, Jingshansi, Tiegukeng, and Xuchang iron deposits in Henan province, as well as the iron deposits in Dongping–Wenshang area in Shandong province. (2) Yuanjiacun-type: Paleoproterozoic clastic sedimentary formation, with magnetite and hematite as the major minerals (20% ≤ TFe < 50%). The Yuanjiacun iron deposit in Shanxi province is generally regarded as belonging to the Superior-type (Cheng, 1957; Shen, 2012; Shen et al., 2005, 2011; Zhai and Windley, 1990; Zhu et al., 1988). Some investigators argue that iron deposits in Huoqiu area of Anhui province and Changyi iron deposit in Shandong province also belong to Superior-type (Lan et al., 2013; Qi, 1987), although this remains controversial. (3) Dalizi-type: Paleoproterozoic clasolite–carbonate formation, with magnetite, hematite and siderite as the major minerals (20% ≤ TFe < 50%). These BIFs belong to the Superior-type, and are represented by Dalizi iron deposit in Jilin province, Tianhu iron deposit in Xinjiang Uighur Autonomous Region and Fengshanying iron deposit in Sichuan province. (4) Xinyu-type: Neoproterozoic banded iron formations (BIFs) with magnetite as the ore mineral (20% ≤ TFe < 50%). These BIFs belong to the Rapitan-type, represented by Yangjiaqiao and Liangshan iron deposits in Jiangxi province and Qidong and Jiangkou iron deposits in Hunan province. (5) Jingtieshan-type: Neoproterozoic BIFs with hematite and specularite as the ore minerals (20% ≤ TFe < 50%). The Jingtieshan iron deposit in Gansu province is the only example identified so far in China. (6) Gongchangling-type: a variety of high-grade iron deposit developed from Anshan-type BIFs by late hydrothermal superimposition. The ores of the deposit are mainly composed of magnetite, with TFe grade higher than 50%, represented by mining area II of Gongchangling iron deposit in Liaoning province. Similar high-grade iron mineralization is also developed in several iron deposits in the Liaoning province, such as Nanfen, Qidashan, Wangjiapuzi and Dagushan, whereas the scale is much smaller than the mining area II of Gongchangling iron deposit. (7) Shilu-type: Neoproterozoic banded iron formations (BIFs), mainly hematite, and the TFe grade is greater than 50%; the Shilu iron