The Major Ore Clusters of Super-Large Iron Deposits in the World, 
Present Situation of Iron Resources in China, and Prospect

ZHAO Yiming*, FENG Chengyou and LI Dixin

Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing, 100037

Abstract: The metamorphosed sedimentary type of iron deposits (BIF) is the most important type of 
iron deposits in the world, and super-large iron ore clusters of this type include the Quadrilátero 
Ferrífero district and Carajas in Brazil, Hamersley in Australia, Kursk in Russia, Central Province of 
India and Anshan-Benxi in China. Subordinated types of iron deposits are magmatic, volcanic-hosted 
and sedimentary ones. This paper briefly introduces the geological characteristics of major super-large 
iron ore clusters in the world. The proven reserves of iron ores in China are relatively abundant, but 
they are mainly low-grade ores. Moreover, a considerate part of iron ores are difficult to utilize for 
their difficult ore dressing, deep burial or other reasons. Iron ore deposits are relatively concentrated 
in 11 metallocenic provinces (belts), such as the Anshan-Benxi, eastern Hebei, Xichang-Central Yunnan 
Province and middle-lower reaches of Yangtze River. The main mineragenetic epoches vary widely 
from the Archean to Quaternary, and are mainly the Late Archean to Middle Proterozoic, Variscan, 
and Yanshanian periods. The main 7 genetic types of iron deposits in China are metamorphosed 
sedimentary type (BIF), magmatic type, volcanic-hosted type, skarn type, hydrothermal type, 
sedimentary type and weathered leaching type. The iron-rich ores occur predominantly in the skarn 
and marine volcanic-hosted iron deposits, locally in the metamorphosed sedimentary type (BIF) as 
hydrothermal reformation products. The theory of minerogenetic series of mineral deposits and 
mineragenetic models has applied in investigation and prospecting of iron ore deposits. A combination 
of deep analyses of aeromagnetic anomalies and geomagnetic anomalies, with gravity anomalies are an 
effective method to seeking large and deep-buried iron deposits. China has a relatively great ore-
searching potential of iron ores, especially for metamorphosed sedimentary, skarn, and marine 
volcanic-hosted iron deposits. For the lower guarantee degree of iron and steel industry, China should 
give a trading and open the foreign mining markets.

Key words: major ore clusters of super-large iron deposits, present situation of iron ore resources in 
China; genetic type; temporal-spatial distribution; ore-searching potential

1 Introduction

Iron and steel production is an important indicator for a 
country’s industrialization level due to our dependency on 
iron and steel in housing, agricultural machinery, 
construction, machinery, automobile, railway, ships and 
military, and iron ores are basic raw materials for iron and 
steel industry.

Since the 21st century, China’s modernization process 
has significantly accelerated, and the rapid development of 
the domestic steel industry has lead to a sharp increase of 
iron ore demands. Most iron ores in China are lean, and 
newly-built iron mines do not keep up with demand.

Hence there is a serious shortage of iron ores, and the 
import of rich iron ores are increasing, making China the 
world’s largest iron ore importer.

This study aims to illuminate the main geological 
characteristics, distribution of the world’s major super-
large iron ore clusters, and present situation of China’s 
iron ore resources, and further the progress and prospect of 
iron ore exploration in the past decade of China.

2 Iron Ore Resources in the World

A summary of the global minerals issued by the US 
Geological Survey in 2012 suggests that, the world’s iron 
ore reserves are 170 billion ton, equivalent to 80 billion
Table 1 Iron ore reserves and production in the world (after U.S. Geological Survey, 2012)

<table>
<thead>
<tr>
<th>Country</th>
<th>Iron ore reserves (million tons)</th>
<th>Iron ore production (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[Iron ore amount]</td>
<td>[Iron metal amount]</td>
</tr>
<tr>
<td>Australia</td>
<td>35000</td>
<td>17000</td>
</tr>
<tr>
<td>Brazil</td>
<td>29000</td>
<td>16000</td>
</tr>
<tr>
<td>Russia</td>
<td>25000</td>
<td>14000</td>
</tr>
<tr>
<td>China</td>
<td>23000</td>
<td>7200</td>
</tr>
<tr>
<td>India</td>
<td>7000</td>
<td>4500</td>
</tr>
<tr>
<td>USA</td>
<td>6900</td>
<td>2100</td>
</tr>
<tr>
<td>Canada</td>
<td>6300</td>
<td>2200</td>
</tr>
<tr>
<td>Ukraine</td>
<td>6000</td>
<td>2100</td>
</tr>
<tr>
<td>Sweden</td>
<td>3500</td>
<td>2200</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>3000</td>
<td>1000</td>
</tr>
<tr>
<td>Iran</td>
<td>2500</td>
<td>1400</td>
</tr>
<tr>
<td>South Africa</td>
<td>1000</td>
<td>650</td>
</tr>
<tr>
<td>Other countries</td>
<td>17800</td>
<td>9200</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>170000</strong></td>
<td><strong>80000</strong></td>
</tr>
</tbody>
</table>

Note: The iron ore reserves issued by the US Geological Survey may be “reserve base” which indicates that the proven resources may satisfy the targets for iron exploitation. The first top 5 countries are Australia, Brazil, Russia, China and India (Table 1). The main producing countries of iron ores are China, Australia, Brazil, India, Russia and Ukraine, accounting for 89% of the world’s iron ore production. China’s iron ore production ranks the first column (with an annual output of 1.2 billion ton), but most are low-grade ores.

It is indicated that the world’s currently proven iron ore reserves can continue for more than 100 years based on the annual consumption of the countries.

3 Major Super-Large Iron Ore Clusters in the World

As suggested previously, the world’s iron ore resources are rich, but they are mostly concentrated in some super-large iron ore clusters. Table 2 and Fig. 1 list the distribution, genetic types of iron ores, iron ore resources and ore grade of the 20 most important super-large iron ore clusters, which occupy more than 80% of the world’s iron ore resources. In our country, we define those 5–10 times the amount of large-scale iron ores as super-large deposits (Tu, 1994; Mei et al., 1997; Pei et al., 2013).

Here we will make a brief introduction on some important and representative super-large iron ore clusters.

3.1 Metamorphosed sedimentary iron deposits

The early Precambrian metamorphosed sedimentary deposits (BIF) are the most important iron ore reserves and production in the world. More than half of the world’s

Table 2 Main clusters of super-large iron ore deposits in the world (from Magagyang, 1955; Shen et al., 1995; and Zhao et al., 2005)

<table>
<thead>
<tr>
<th>Number</th>
<th>Ore cluster</th>
<th>Genetic type</th>
<th>Iron ore amount (billion ton)</th>
<th>Ore grade (Fe wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kursk in Russia</td>
<td>Sedimentary-metamorphic type, with late weathering and leaching</td>
<td>39</td>
<td>54-62</td>
</tr>
<tr>
<td>2</td>
<td>Kerrey warlock in Ukraine</td>
<td>Sedimentary-metamorphic type</td>
<td>20.1, containing 1.4 billion ton rich ores</td>
<td>25-43</td>
</tr>
<tr>
<td>3</td>
<td>Kerch in Ukraine</td>
<td>Sedimentary type</td>
<td>5</td>
<td>20-51</td>
</tr>
<tr>
<td>4</td>
<td>Kaj Khanal in Russia</td>
<td>Magnatic type</td>
<td>12.2</td>
<td>14-57</td>
</tr>
<tr>
<td>5</td>
<td>Kiruna in Sweden</td>
<td>Marine volcanic rock type</td>
<td>5</td>
<td>30-70</td>
</tr>
<tr>
<td>6</td>
<td>Anshan-Benxi in China</td>
<td>Sedimentary-metamorphic type</td>
<td>18</td>
<td>33</td>
</tr>
<tr>
<td>7</td>
<td>Eastern Hebei in China</td>
<td>Sedimentary-metamorphic type</td>
<td>7.5</td>
<td>31</td>
</tr>
<tr>
<td>8</td>
<td>Panzhihua-Xichang in China</td>
<td>Magnatic type vanadium titanium magnetite</td>
<td>5.7</td>
<td>27-37</td>
</tr>
<tr>
<td>9</td>
<td>Bihar-Orisa in India</td>
<td>Sedimentary-metamorphic type, with late weathering and leaching</td>
<td>2.7</td>
<td>&gt;60</td>
</tr>
<tr>
<td>10</td>
<td>Central Indian State</td>
<td>Sedimentary-metamorphic type, with late weathering and leaching</td>
<td>7.8</td>
<td>60-69</td>
</tr>
<tr>
<td>11</td>
<td>Haji Fagafaga J of Afghanistan</td>
<td>Magnatic type</td>
<td>2</td>
<td>62</td>
</tr>
<tr>
<td>12</td>
<td>Lorraine in France</td>
<td>Marine sedimentary type</td>
<td>7.7</td>
<td>31-37</td>
</tr>
<tr>
<td>13</td>
<td>Bushveld in South Africa</td>
<td>Magnatic type vanadium titanium magnetite</td>
<td>2.2</td>
<td>42-60</td>
</tr>
<tr>
<td>14</td>
<td>Hamesley in Australia</td>
<td>Sedimentary metamorphic hydrothermal deformed type</td>
<td>32</td>
<td>54-64</td>
</tr>
<tr>
<td>15</td>
<td>Turgai in Kazakhstan</td>
<td>Magnatic type (?</td>
<td>14.2</td>
<td>40.6</td>
</tr>
<tr>
<td>16</td>
<td>Minas-Gerais in Brazil</td>
<td>Sedimentary-metamorphic type, with late weathering and leaching</td>
<td>30</td>
<td>60-65</td>
</tr>
<tr>
<td>17</td>
<td>Caracas in Brazil</td>
<td>Sedimentary-metamorphic type, with late weathering and leaching</td>
<td>17.88</td>
<td>59-66</td>
</tr>
<tr>
<td>18</td>
<td>Lako in Chile</td>
<td>Magnatic type</td>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>19</td>
<td>Lake Superior in America</td>
<td>Sedimentary-metamorphic type</td>
<td>16.2</td>
<td>25-45</td>
</tr>
<tr>
<td>20</td>
<td>Labrador in Canada</td>
<td>Sedimentary-metamorphic type</td>
<td>20.6</td>
<td>36-38</td>
</tr>
</tbody>
</table>
20 more super-large iron ore clusters are of this type (Table 2), occupying about 60% of the world’s total iron ore reserves. Among them, rich iron ores account for a large proportion, i.e., more than 70% of the world’s total rich iron ore reserves. These rich iron ores are mainly formed by weathering leaching or later hydrothermal alteration of banded iron formations (TFe 25%–35%) to remove silicon and concentrate iron, and their TFe content can reach as great as 52%–67%, such as iron ore clusters of the Kursk in Russia, Kerrey Worlock in Ukraine, Minas-Gerais in Brazil, central India Province and Hamesley in Australia. Klein (2005) proposed that, the formation age of BIF in the world falls in a narrow age of 2700–2000 Ma.

3.1.1 Kursk in Russia

The Kursk magnetic anomaly area, located in the middle part of European Russia, is one of the world’s largest metamorphosed sedimentary iron ore clusters. It covers an area of 15×10^4 km², extending up to 600 km², and includes Mikhailov, Yakovlev, Marinoff, Goss Ki Scherf and Biel. The proven iron ore reserves are 55.6 billion ton, including 39.1 billion ton rich ore reserves at an iron grade of 54%–62% (TFe) (Shen et al., 1995).

The Kursk iron ore magnetic anomaly zone is a hidden metamorphosed sedimentary iron ore cluster. The iron-bearing metamorphosed strata are covered by the Devonian, Carbonaceous, Jurassic, Cretaceous, Tertiary and Quaternary sedimentary strata of the Russia platform. The sediments vary from 30–40 m to 650–670 m in thickness. The banded iron-bearing metamorphosed rock series have a NW-trending zonal distribution, and the isoclinal folds resulted in 2–7 iron ore beds, with every iron ore bed ranging from 200 to 500m thick. The first author conducted one and a half months of filed work in the Yakovlev rich iron deposit of the Kursk magnetic anomaly area, the former Soviet Union in 1958, and cataloged a large number of rock and ore cores to write a graduation thesis. It is shown that the rich iron ores were formed by paleo weathering leaching of banded metamorphosed sedimentary poor ores (BIF) to remove silicon and concentrate iron, belonging to facial weathering crust. The rich iron ore beds occur in unconformities below the Russian platform covers, with their thickness varying from 100 m to more than 300 m. The width of the rich iron ore beds depend on the width of these banded poor iron ore beds, and range from 300m to 500m. Roof and floor wall rocks of these BIFs are phyllite, locally changing to bauxite by strong paleo weathering leaching. The rich iron ore beds were unconformably covered with about 500m thick Devonian-Quaternary sedimentary cover, and contain 7 aquifers. Thus, those rich iron ores are difficult to be mined. The rich iron ores display blue-gray porous and loose structure, and are composed of martite, with minor foliated hematite and not completely leached quartz. The grade of TFe is as great as 58%–62%.

For the ore searching of hidden rich iron orebodies in this area, a combined ground magnetic method with gravity measurements is effective. Magnetic method can delineate the accurate position of the banded iron-bearing quartzite (BIF), and weathered crust type martite rich iron orebodies can thus be discovered in those positions with weak magnetic anomalies and strong gravity anomalies.

3.1.2 Hamersley in Australia

The Hamersley iron basin is located between the Pilbara block and Yilgarn block in Western Australia. The iron-bearing strata include the Neoarchean-Paleoproterozoic sedimentary rocks and volcanic rocks. The former rocks are dominated by sandstone, shale and dolomite, and the latter are composed of volcanic lava and pyroclastic rocks. This set of strata is called the Hamersley group, formed ca. 2500–2300 Ma (Muller et al., 2005; Wang et al., 2011). The major iron ore beds are hosted in the Hamersley group, and are composed of shale-dominated sedimentary rocks, interbedded with volcanic rocks and dolerite sills.

The Hamersley group is hosted in a broad basin extending 300 km in length and 160 km in width. The overall trend of the tectonic belt is in a NWW direction. Iron ore deposits are concentrated in the central southern part of this basin, and the most important ore bed has a thickness of >650m (intercalated with shale). It has a high iron grade (TFe), reaching up to 52%–64%. The ores are dominated by platy hematite and martite, with small amounts of goethite and quartz. The proven iron ore reserves in the ore district reach 32 billion ton, and contains 24.9 billion ton iron ore reserves at an iron grade of 54%–64% (Shen et al., 1995).
There has been considerable debate about the genesis of the deposit. Taylor et al. (2001), Brown et al. (2004) and Jiang et al. (2013) considered that the rich iron ores were formed by the late hydrothermal alteration of the banded poor iron ores (BIF). Martin (1999) and Wang et al. (2011) suggested that, sedimentary strata of the preliminary rich iron ores were formed during submarine hydrothermal exhalation, and were further enriched under hypergenic processes since the Mesozoic (Lascelles, 2006). The authors have systematically observed some ore polished thin sections under microscopes; these polished thin sections from the Hamersley iron deposit were provided by Comrade Yue Xinshin, the chief engineer of the Geology and Mineral Resources Department, the former Ministry of Geology and Mineral Resources. These ores display fine striped dense structure, unlike the porous and loose rich iron ores from the Kursk ore district in Russia. Therefore, the opinions of Martin (1999) and Wang et al. (2011) seem to be somewhat reasonable. However, the late hydrothermal alteration, weathering leaching and enrichment are still lack of evidence. Therefore, the enrichment of the iron ores may be of multiple genesis.

3.1.3 Minas-Gerais in Brazil

Brazil is a world-class important production country of rich iron ores, and there are three main production bases: Minas-Djilas (iron quadrilateral), Carajas and Urukum bordered with Bolivia. This study will focus on the Minas-Djilas ore cluster. It has iron ore reserves of 22 billion ton, and contains ore reserves of 10 billion ton at a grade of 40%–65% TFe (Shen et al., 1995).

The Minas-Djilas area, located in the Minas State southeast of Brazil, is also called the iron quadrilateral area for its roughly quadrilateral shape in the plane, reflecting the distribution of the Minas supergroup composed of banded iron formations (BIF). This supergroup has undergone regional metamorphism of low-grade greenschist to middle-low amphibolite facies. The western part of this area is dominated by iron tremolite and cummingtonite metamorphic belt, while the east is mainly actinolite and tremolite-anthophyllite metamorphic belt. High-grade iron ores are commonly fine-grained massive and stripped, grey-blue gray, and are mainly composed of hematite, martite and small amounts of specularite, with some pores developed in strips. Gangue minerals include minor quartz, dolomite and chlorite. Hard ores are composed of magnetite. Hartman et al. (2006) conducted U-Pb SHRIMP dating on the euhedral zircon from the Caraca ore-bearing group, and yielded an age of 2580±7 Ma, belonging to the late Archean.

The formation of the iron ore deposits has undergone multistage of ore-forming processes (Ramanaidou et al., 1996; Rosiere et al., 2004; Guo et al., 2013). In the first stage, original banded iron formations (BIF) were formed in the Archean-Proterozoic. In the second stage, metamorphic hydrothermal fluids associated with the Pan Amazonian orogeny interacted with BIF to form magnetite-rich high-grade orebodies and dolomitic rich iron ore embryo in dolomitic iron quartzite. In the third stage, magnetite and rich iron dolomite formed blue-gray high-grade hematite-marite orebodies after undergoing supergene leaching.

3.2 Magmatic iron ore deposits

These orebodies, also referred to V-Ti magnetite deposits, are intimately associated with different ages of mafic and ultramafic complex in genesis, and occur in some certain positions of the rock bodies. They generally occur in deep fault zone at marginal uplift areas or their adjacent regions. The world’s super-large iron ore clusters of this type include the Panzhuhua-Xichang in Sichuan Province of China, Bushveld in South Africa and Kajikanar in Ural of Russia. The proven iron ore reserves of magmatic iron deposits occupy 7%–10% of the world’s iron ore reserves. These ores are rich in vanadium and titanium.

The Bushveld igneous complex in South Africa contains the largest metal endowments in the world. It has the world’s largest chromite and platinum metal deposits, and also V-Ti magnetite deposits. This igneous complex extends 450 km in its EW direction, 250 km in its NS direction, and is dominated by diorite, gabbro, troctolite and hypersthene-fels. From the top to the bottom, it can be divided into the upper rock belt (5000 m thick), main rock belt (10000 m thick) and key rock belt (3500 m thick). V-Ti magnetite orebodies are mainly hosted in the upper rock belt and the upper part of the main rock belt; iron ore beds in the upper rock belt are stable along strike, and can extend as long as 322 km, while iron ore beds in the main rock belt are not stable. The V-Ti magnetite orebodies in the upper rock belt and the upper main rock belt have 26 layers, with every single bed ranging from 2 to 20 m in thickness. The grade of iron (TFe) is as high as 55.8%–57.5%, V₂O₅ 1.4%–1.66%, TiO₂ 12.2%–13.9% (Shen et al., 1995). This iron deposit has ore reserves of 2.2 billion ton. The rock-forming and ore-forming age of the Bushveld deposit was 2050–2060 Ma, belonging to the Paleoproterozoic, and its metallogenic tectonic setting is in a continental margin rift environment (Lü et al., 2011).

3.3 Volcanic-hosted iron ore deposit

This type of deposits refers to those with their ore-forming processes related to volcanic activities. They can be divided into marine volcanic type and continental
volcanic type based on their formation environments, and the former dominates. Volcanic-hosted iron deposits account for about 10% of the world’s iron ore reserves. There are 4 super-large volcanic-hosted iron ore clusters in the world, i.e., the Kiruna in Sweden, Hajigak in Afghan, Lako in Chile and Tuerkai in Kazakhstan (Table 2).

3.3.1 Kiruna ore cluster in Sweden
This deposit, located in the Lapland area north of Sweden, is so far the world’s largest apatite-magnetite iron formation hosted in intermediate-acidic volcanic rocks. It occurs in the Palaeoproterozoic (1900–1880 Ma) sodium-rich volcanic rock series. Orebodies display a NS-trending bedded shape, and the main orebody is hosted between the keratophyre (or syenite) and quartz porphyry, 4.7 km long, 20–200 m thick, extending 1700 m. The orebodies have a conformable contact with wall rocks, and commonly develop albition and potassium feldspathization in the contact zone. The total iron ore reserves amount to 3.4 billion ton at a high grade of 58%–70% TFe (Xie et al., 2003; Wang et al., 2013).

3.3.2 Hajigak in Afghan
The deposit is located in the middle part of Afghanistan. The ore-hosted wall rocks are the Silurian and lower Devonian shale, sandy shale interbedded with dolomite lenses, lava and mafic tuff, and the iron ores and mafic volcanic rocks are in the same strata. The orebodies are lenticular, 8 km long, and can be subdivided into 5 ore sections, reaching up to 50 m in its maximum. The ores are dominantly platy hematite, associated with small amounts of magnetite and pyrite. Gauge minerals include chlorite, quartz and albite. The TFe grade is high, averaging 62%, and the iron ore reserves are estimated to be >2 billion ton, favorable for open pit mining.

The genesis of this deposit may be related to the marine mafic volcanic eruption (Shen et al., 1995).

3.3.3 Lako in Chile
The Lako iron deposit is located in the high Andes Mountains north of Chile, and has attracted much attention among geologists for its lava flow features. It is composed of 5 large magnetite lavas, and the reserves are estimated to be 1 billion ton at a grade of 65% TFe. The Lako area is an ancient caldera, and the 5 lava flow orebodies are related with the sub-crater around the main crater. The core of the caldera is a pillar body of rhyolite dacite, surrounded by the Lako volcanic complex composed of andesite, pyroclastic rocks, ignimbrites and magnetite lava flow. The Lako volcano has a young age of Pliocene-early Pleistocene. The iron orebodies are similar to lava flow in shape. The ore composition is simple, consisting of magnetite, hematite and martite, with small amounts of apatite and actinolite. The ores contain a large amount of porous basalt lava flow (Shen et al., 1995).

3.3.4 Tuerkai in Kazakhstan
The Tuerkai ore cluster in Kazakhstan is the largest volcanic-hosted one, located in the Tuerkai depression area north of Kazakhstan. The ore belt extends in a nearly NS direction along the eastern Ural slope, 800–1000km long and 100–150km wide in its EW direction, and include the large Sarbai, Kachal, Sokolov and Kurlukur deposits. The total ore belt contains 14.2 billion ton proven iron reserves and comprises the early Carboniferous sedimentary-extrusive rocks. The orebodies are stratoid or lenticular, and the ore-hosted wall rocks are limestone lenses -bearing tuff and volcanic breccia, associated with andesitic porphyrite and diorite porphyrite intrusions. The ores are densely massive or disseminated, composed of magnetite and small amounts of pyrite, pyrrhotite, chalcopyrite and sphalerite. Gangue minerals are clinopyroxene, scapolite, garnet, wollastonite, albite, epidote, antinolite, quartz and calcite. Wall rock alteration is dominated by skarnization and chlorine scapolitaization. The ores have a grade of TFe 29%–41% (Metallurgical Geological Institute of Guilin, 1976).

3.4 Sedimentary iron deposits
Deposits formed by sedimentation are called sedimentary deposits. They can be divided into continental and marine sedimentary types, and the latter ones have a larger scale. Most iron sedimentary deposits are formed by chemical processes, and some are beach sandstones. Their ages vary widely from the Proterozoic to Quaternary, and their distribution also has a wide range. This type of iron deposits have proven reserves of >32 billion ton, but the iron grade is relatively poor, even some having high phosphorus content. This type of deposits accounts for about 12% of the total world’s iron ore reserves.

The largest sedimentary iron ore cluster in the world is the Lorraine in France and Kerch in Ukraine, which we will introduce in the following.

3.4.1 Lorraine in France
The Lorraine iron deposit in the Lorraine area of northeastern France is the largest sedimentary iron deposit in the world, and is also the largest iron deposit in Western Europe. It covers an area of 1100 km², and extends to the territory of Luxembourg in its east. The deposit occurs in the Jurassic sedimentary strata, forming a giant syncline basin. The iron reserves are in excess of 7.7 billion ton, and the ore-bearing beds have a thickness of 10–60 m, including 12 iron ore beds and 1–6m for single ore bed.
The interbedded ore beds contain sandstone and limestone. The ores display an oolitic structure, and the small oolitic grains have diameter of 0.15–0.5 mm. These grains are composed of hydrogoethite and phosphorus limonite (a variant of siderite), containing iron chlorite, siderite and hematite. The cement has a similar composition with oolitic grains. The ores contain 31%–36% TFe, 0.5%–1.8% phosphorus, and high calcium content. Therefore, the ores can form calcium silicate slag without solvent in blast furnace (after Magagyang, 1955).

3.4.2 Kerch hematite deposit in Ukraine

The Kerch hematite deposit is situated in the Kerch peninsula of Ukraine. It contains chamsoite and limonite associated with lenticular and oolitic siderite in the Tertiary marine sedimentary layers, and is typically formed under paleo-oceanic and swamp environments. It covers a mineralized area of 150 km². The ore beds are gentle, with dips only 10°–15°, and their thickness can reach up to 25–30 m. The ores consist of chamosite, limonite, hydrogoethite, berthierite, siderite, hematite and barite, with a TFe grade of 20%–51%, averaging 36%; they have high Mn content, regionally greater than 3%, and 0.4%–1.5% P. The iron reserves amount to 5 billion ton (after Magagyang, 1955).

4 Present Situations of China’s Iron Ores

China has a vast territory and complicated geological conditions, and has undergone multistage tectonic movements during the long geological periods. The iron resources in China are abundant, and have a wide but concentrated distribution. The iron deposits have various types, and are featured by many lean ores and few rich ores. The ore types are complicated, and most ores are easy to be dressed, with many associated beneficial components and great difficulties of comprehensive utilization.

4.1 Iron ore resources and distribution

China has more than 3000 proven iron production bases, with accumulated iron ores of 51.913 billion ton in 1997 (Zhao et al., 2005), 61.335 billion ton in 2007 (China Geological Survey, 2008), 72 billion ton in 2009 (62 billion ton recoverable iron ores) (Li et al., 2012) and as great as 84 billion ton proven iron ores in 2011 (informed face to face by Li, 2012; Hao et al., 2013; Huang et al., 2014).

The proven iron ores are concentrated in Liaoning, Hebei, Sichuan, Anhui, Shandong, Yunnan, Shanxi, Hubei, Inner Mongolia, Xinjiang and Henan provinces (autonomous regions). China’s iron deposits often occur in clusters or zones, and comprise some important iron ore clusters (belts), such as the Anshan-Benxi, Xichang-middle Yunnan Province, Eastern Hebei Province-Miyun county, Wutai-Lvliang, middle-lower reaches of Yangtze River, Baotou-Baiyumebo, Handan-Xingtai, East Tian Shan- West Tian Shan, middle Shandong Province, Huoqui and western Hubei Province-northern Hunan Province. These 11 iron ore clusters (belts) have about 80% of the proven iron ores in China.

As suggested above, the iron resources in China have an even distribution. Except the west and east Tian Shan in Xinjiang and Xichang-middle Yunnan Province, the other 9 metallogenic areas (belts) are distributed in the middle-eastern part of China (Fig. 2).

Although the proven iron ores in China have amounted to more than 80 billion ton, a considerable part of them are difficult to utilize due to the difficulties to dress, very deep burial and complicated hydrogeological conditions. Song (1996) proposed that, the iron ores which are difficult to utilize currently reach up to 18.5 billion ton, about 38.6% of the recoverable iron ores in the year.

4.2 Genetic types and geological features

Cheng et al. (1978; 1994), Yao et al. (1993), Zhao et al. (2004), Li et al. (2012) and Zhang et al. (2014) have systematically studied the types, geological conditions and spatial and temporal distribution of the iron deposits in China. The iron deposits in China can be divided into magmatic type (11.6%), volcanic-hosted type (5.2%), skarn type (10.4%), hydrothermal type (3.3%), metamorphosed sedimentary type (57.7%), sedimentary type (10.4%), weathering leaching type (1.2%) and other types (3.7%) (Zhao et al., 2004). The following chapters will describe their geological features briefly, and the deposit types are ranked by endogenous, metamorphosed sedimentary, sedimentary and hypogene types.

4.2.1 Magmatic iron deposits (also referred to V-Ti magnetite deposit)

This type of deposits is concentrated in the Panzhihua-Xichang area in Sichuan, Daminia and Heishan in Hebei Province.

The iron deposits in Panzhihua-Xichang area are products of late magmatic crystallization differentiation. The orebodies occur in the lower and bottom parts of gabbro or ultramafic rocks (Clinopyroxene peridotite-clinopyroxene olivine pyroxenite-clinopyroxenite-gabbro series) as stratoid shapes. Some rockbodies display multilayer rhythm features. The rock-forming and ore-forming ages are the late Hercynian (255–260 Ma) (Xie et al., 2005; Cheng et al., 2013). The ores are dominated by titanium magnetite, ilmenite, plagioclase, augite, hyperthene, actinolite and chlorite, with a small amount of
aplite and metal sulfides.

Iron deposits in the Damiao-Heishan area are generally penetration type ones formed in the late magmatic periods. The ores are hosted in the tectonic fissures of anorthosite complex, and occur as lenticular and veined shapes in clusters. The SHIRM U-Pb age of zircons from the hosted anorthosite is 1726±9 Ma (Zhang et al., 2007), of the middle Proterozoic age.

Both iron deposits have iron (TFe) contents ranging from 25% to 45%, TiO₂ 5%–15% and V₂O₃ 0.2%–0.5%.

4.2.2 Volcanic-hosted iron deposits

This type of deposits can be divided into continental volcano-intrusive deposits and marine volcano-intrusive deposits based on geological environments of their ore-hosted volcanic rocks series.

The continental volcano-intrusive iron deposits are distributed mainly in the Mesozoic continental volcanic basins in the Ningwu-Luzong area. The orebodies occur in the outer and inner contact zone of subvolcanic rocks (diorite porphyrite). The ores mostly have middle or slightly low iron grade (TFe 22.27%–45.98%), and only few deposits have iron ores with TFe grade reaching rich iron ores (50.92%), such as the Meishan in Jiangsu Province.

Based on formation mechanisms of marine volcanic-hosted iron deposits, they can be subdivided into marine volcanic-hosted sedimentary and marine volcanic-hosted hydrothermal types. The former are represented by the Shilu iron deposit in Hainan and Shikebutai iron deposit in western Tian Shan of Xinjiang. The orebodies occur as stratoid and lenticular shapes, and the ores are generally massive hematite. Rich iron ores occupy a considerable part, and quite a few ores belongs to those used in steelmaking, whose TFe content reaching 60.4%–62.31%; some are used for iron making. The latter ones are the Dahongshan deposit in Yunnan and Zhibo deposit in West Tian Shan of Xinjiang, and both of them are large-scale. In addition, the Zhibo iron deposit is associated with a number of large and medium-sized skarn deposits, such as the Beizhan, Dunde, Chagannur and Songhu deposits. Their ore-hosted wall rocks are the Carboniferous andesitic tuff interbedded with marble, and the related intrusive rocks include diorite, granodiorite, quartz diorite.
and granite, with undeveloped intrusive rocks in some deposits. The orebodies occur as lenticular, stratoid and vein-shaped. The ores have metal minerals dominated by magnetite, with some pyrite, chloropyrite, specularite and sphalerite; gangue minerals include granit, diopside, epidote, actinolite, chlorite and calcite. The ores have iron grade (TFe) ranging from 20% to 64%, averaging 40%. Wall rock alteration is predominated by skarnization (Zhang et al., 2012a, 2012b; Wang et al., 2012; Jhaj et al., 2012). Thus, their characteristics are similar to the volcanic-hosted iron deposits in the Tuergai area north of Kazakhstan.

4.2.3 Skarn iron deposits (also referred to contact metasomatic deposit)

They are widely but unevenly distributed in China except Tianjin, Taiwan, Chongqing and Guizhou, and are concentrated in the central North China Platform, middle and lower reaches of Yangtze River, southern Fujian Province, eastern Guangdong Province, East Qin Ling, Eastern Xinjiang and eastern Kunlun area (Fig. 2).

The orebodies occur as lenticular shapes in the contact zone between intermediate (acidic) intrusive rocks and carbonate rocks. The ores are mainly rich, with TFe content varying from 40% to 55%, but some contain high sulfur and copper content, and should be first dressed to be in furnace. The ore minerals are mainly magnetite, with small amounts of martite, pyrite, chalcopyrite, bornite, sphalerite and galena. Gangue minerals are diopside, garnet, epidote, actinolite, calcite and quartz. The ore-related intrusions in eastern China were mostly formed in the Yanshanian period, and those in western China were partly formed in the Indosinian, such as the Galinge, Kendemake and Yemaquian Fe-polymetallic deposits in western Qinghai Province (Zhao et al., 2013). The ore-related intrusions are mainly diorite, quartz diorite, monzonite, granodiorite and granite, and few deposits have gabbros and diske diores. Alkali metasomatism is commonly in the contact zone of intrusions, mostly albitization and scapolitization, and potassiumfeldspathization can be observed in some iron deposits associated with multiple metals. Skarn associated with iron deposits is mainly calcareous skarn, with few magnesium skarn (Zhao et al., 2012).

Mineralized wall rocks in eastern China are mostly the middle Ordovician limestone and dolomitic limestone (Handan-Xingtai area in Hebei, Jinan and Laizu in Shandong), Triassic limestone and dolomitic limestone (southern Fujian Province), Carboniferous-Triassic sandstone and limestone (southern Fujian Province), and the east Qinglin area is dominated by the Proterozoic dolomite (Mulonggou and Heishan in Shaanxi Province).

4.2.4 Hydrothermal iron deposits

This type of iron deposits only occupy a small proportion (3.3%) of China’s iron ores, but they are the main source of rich iron ores. The orebodies show a significant tectonic control by fault structures, and occur as lenticular or veined shapes. The wall rocks are mostly carbonate rocks of different ages. They can be subdivided into high-temperature hydrothermal and middle-low temperature hydrothermal types based on the relationship between iron ore formation and intrusions, and their formation conditions.

The high-temperature hydrothermal deposits occur as lenticular or veined shapes in the contact zone of intermediate (acidic) intrusions and its adjacent wall rocks. Compared with skarn iron deposits, they have no typical skarn mineral assemblages, but have significant wall rock alteration, such as actinolitization, tremolitization, epidotization, serpentinization and siliciification. The ore minerals are mainly magnetite, with hematite, pyrite and pyrrhotite. Gangue minerals are the same to altered minerals. Most ore grade is rich, reaching up to 50%–65%. Examples are the Lingxiang in Daye of Hubei, Lugu iron mine and Dadingshan in Sichuan.

Middle-low temperature hydrothermal iron deposits have no significant relationship with intrusive rock bodies. The orebodies are controlled by regional faults, occurring as lenticular and veined shapes. Wall rock alteration is dominated by chloritization, sericitization, siliciification and carbonation. Ore minerals are mostly siderite, with hematite and limonite, associated with few pyrite, chalcopyrite, galena and sphalerite. Limonite is the weathering products of siderite in the surface. Gangue minerals are the same to alteration minerals, with some barite and chalcedony. Examples are Guanyinshan in Guizhou, Huanian, Shangchang and Wangjiata in middle Yunnan area, and Wendeng and Dianzi in Shandong. The ore grade (TFe) is generally from 40% to 47%.

4.2.5 Metamorphosed sedimentary iron ore deposits (BIF)

This type is the most important iron deposit type, and is mainly distributed in Anshan-Benxi, eastern Hebei Province, Wutai-Lvliang in Shanxi Province and middle Inner Mongolia in the north of the North China Platform, and regional basement uplift in the North China Platform. As mentioned above, the orebodies mainly formed in the early Precambrian, especially the late Archean and Proterozoic. The orebodies occur as bedded, stratified or lenticular shapes in metamorphosed rock series, and have the same occurrence with wall rocks. The ores display banded or striped structure, and the strips are 1–5 mm in width, composed of interbedded quartz with magnetite.
The ores are mainly low-grade, with iron grade (TFe) varying from 25% to 36%. Few mines have high-quality rich ores formed through the late hydrothermal alteration, such as the Gongchangling and Yingtaoyuan ore districts in Anshan of Liaoning; the ores are densely massive, and the average iron grade can reach as great as 64.81% (Zhao et al., 2004).

Banded iron formations (BIF) in China are generally not large-scale, with their maximum scale extending no more than 10 km. The thick ore beds can be several tens of meters to about 200 m. The ore-hosted wall rocks show a significant control by lithology and metamorphism of primary rocks, such as amphibolite, granulite, phyllite and sercite chlorite schist. Some ore districts have highly metamorphosed gneiss and granulite.

Metal minerals in ores are dominated by magnetite, and martite can be observed in the near-surface orebodies due to oxidation. Gangue minerals are principally quartz, with few silicate minerals, such as hornblende, biotite, diopside, cummingtonite, grunerite, actinolite and ankerite. In some iron ores of granulate facies in eastern Hebei Province, hypersthene and garnet can be seen.

4.2.6 Sedimentary iron deposits

This type of widely distributed deposits occurs in nertic facies, marine-continental alternating facies and lacustrine environments during many geological periods after the Mesoproterozoic. Of the most important are the middle Proterozoic Changcheng System Xuanlong-type iron deposits and the middle-upper Devonian Ningxingqian type iron deposits, belonging to nertic facies sedimentary ones. The former are distributed in the Xuanhua-Longguan-Chicheng area of Zhangjiakou, and the latter are concentrated in western Hubei-northeastern Hunan Province. The ores display stratoid shapes, with stable ore horizons. The ores are mainly hematite, associated with siderite and chamosite; they have middle iron grade, with TFe contents varying from 30% to 50%, but have high phosphorous content, about 0.5%–1%. Most Ningxiang type iron deposits are difficult to use for the reason of ore beneficiation.

In addition, there are marine-continental alternating facies or lacustrine sedimentary iron deposits in Shanxi, Sichuan, Guizhou and Yunnan Provinces, and their formation ages are dominated by the Carboniferous, Permian, Triassic and Jurassic. Some iron ore beds are generally related with coal-bearing strata; some iron deposits are associated with bauxite deposits, such as those in Guizhou and Shanxi Provinces, and often occur at the bottom of the bauxite beds. The ore beds display bedded, stratiform or lenticular shapes, and vary greatly along the strike. The deposits are often middle- to small scale. The main ore mineral is siderite, with hematite and also different amounts of chamosite. The ore grades are middle, and most are featured by low sulfur content and high phosphorus content (Cheng et al., 1994).

4.2.7 Weathering leaching iron deposits

This type of deposits are formed from different types of siderite deposits, metal sulfide deposits or other iron-bearing rocks by weathering leaching under hot and humid climates and suitable terrains and tectonic conditions. They are mostly middle- to small-scale.

Based on types of primary deposits or iron-bearing rocks, they can be subdivided into: ① gossan by weathering of siderite (such as the Dabaoshan in Guandong, Heiwang in Shandong and Quxiang in Guangxi); ② weathering gossan of pyrite or other metal sulfide deposits, such as Dajiangping in Guangdong, Xinqiao in Anhui and Jian’ai in Fujian; ③ weathering crust of iron-bearing andradite and hedenbergite skarn, such as the Wanhuhu and Taihua in Fujian and Tiekeng in Jiangxi; and ④ basalt weathering residual iron deposits, such as the Lincheng in Hainan, sometimes containing a certain amount of pyrolusite and psilomelane. Gangue minerals may contain quartz, calcite, dolomite, kaolinite and chlorite. The ore grade (TFe) is in the range of 35%–45% (Zhao et al., 2004).

4.2.8 Other types of iron deposits

These refer to those with considerable debate of their genetic types and difficult to define, such as the Baiyunhe rare earth iron deposit in Inner Mongolia and Wengquangou boron-iron deposit in Liaoning Province.

4.3 A brief introduction of important iron metallogenic areas (belts) in China

As mentioned above, China has 11 important iron ore metallogenic belt, i.e., the Anshan-Benxi, Xichang-middle Yunnan Province, eastern Hebei Province-Miyun county in Beijing, Wutai-Lvliang, middle-lower reaches of Yangtze River, Baotou-Baiyunebo, Handan-Xingtai, east Tianshan-west Tianshan, middle Shandong Province, Huoqu and western Hebei Province-northwestern Hunan Province. Their iron ores account for about 80% of the total iron ores in China. Five important and typical iron ore metallogenic belt will be focused on.

4.3.1 Anshan-Benxi iron ore district

The Anshan-Benxi area, located in the northeastern Jiao-Liao platform uprise northeast of the North China Platform, is a key iron metallogenic area in China. The Precambrian metamorphosed rock series are composed of the Neoarchean Anshan group and the Proterozoic Liaohe
group, and banded siliceous iron formations (BIF) are mainly hosted in the Anshan group. The proven iron ores of a large number of large-scale, superlarge and medium-small deposits, such as the east Anshan, west Anshan, Qidashan (Yingtaoyuan), Yanqianshan, Gongchangling, Huijiamiaozi (Hongqi), Nanfen and Waitoushan, amount to >12.5 billion ton (according to the proven iron ores in 1997, the same below), accounting for 24.2% of the total iron ores in China.

The Anshan group metamorphic rock series in this area is actually the remains of large granite bodies (Fig. 3), and can be divided into the lower Anshan group, middle Anshan group and upper Anshan rock group. They each have different metamorphic degrees and varying iron ore geological features.

Iron deposits hosted in schist facies-low amphibolite facies metamorphic rock series of the Anshan group comprise of a thick main seam, associated with 1-2 small seams. The main seam is 100–300 m thick, extending up to 10 km. They are large or superlarge, such as the east Anshan, west Anshan, Qidashan and Yanqianshan.

Iron deposits hosted in the amphibolite facies metamorphic rocks series of the middle Anshan group generally contain densely multi-layer iron seams. The single seam is 20–60 m, and the accumulated seams reach up to 160 m in thickness, extending several hundred meters to 4.5 km. They are mostly large-middle sized and small. Examples are the Gongchangling, Nanfen, Waitoushan and Xiaolingzi.

Iron deposits occurring in the amphibolite and granulite facies of the Anshan group are sparsely multi-layer orebodies, mostly small scale. The single seam is 10–20 m, and the accumulated seams are 20–40 m thick. An example is the Luobukan.

The iron deposits in this area are mostly banded siliceous lean iron ores, with iron grade (TFe) varying from 27% to 35%, but large-scale hydrothermal rich iron deposits can be observed in the Gongchangling ore district. Rich orebodies are controlled by the thrust fault in the banded lean ores (Cheng, 1957). In the Qidashan (Yingtaoyuan) and Wangjiabaozi ore districts, rich iron orebodies can also be observed, but have a small scale.

4.3.2 Xichang-middle Yunnan iron metallogenic belt
This belt is structurally situated in the Xikang-Yunnan axis in the western margin of the Yangtze Platform (Ren et al., 1980). It is an NE-trending inherited multicyle iron metallogenic belt, and has proven iron ores exceeding 7 billion ton (according to proven iron ores in 1997, the same below), accounting for 13.7% of the total iron ores in China, and just following the Anshan-Benxi area.

Iron deposits formed the earliest are the volcanic-hosted-sedimentary Dahongshan iron (copper) deposits hosted in the Paleoproterozoic Dahongshan group metasomatic volcanic rocks. In the Neoproterozoic, a series of contact metasomatic iron deposits are formed, such as the Lugu and Lake deposits.

Iron deposits formed later are magmatic V-Ti magnetite...
deposits hosted in mafic-ultramafic rockbodies. This type of iron deposits are the most important ones in this metallogenic belt, and are distributed in the Mianning in the north and Jinsha River in the south, along the west Anninghe fault, extending 320 km (Fig. 4). These deposits are developed in the Mouding of Yunnan Province, but are far smaller than those in Sichuan Province. Typical deposits are the Panzhihua, Hongge, Taihe, Baima and Baicao deposits, and are all large or superlarge ones.

Different ages of sedimentary iron deposits are also developed in the covers of the Xikang-Yunna axis, and are distributed in the east of the Anninghe-Yimen deep fault. Of the more important are the Huatan type iron deposits in the middle Ordovician and the Bijishan and Yuzidian iron deposits in the middle Devonian.

In the carbonate formations and volcanic-sedimentary clastic rocks of the middle Proterozone Fengshan group in the Xichang area and the middle Proterozone Kunyang group in the middle Yunnan Province, siderite-dominated sedimentary-hydrothermal alteration iron deposits are widely distributed, such as the the Fengshanying in Huili, Lukuishan in Xiping and Wangjiatan in Anning.

4.3.3 Eastern Hebei-Miyun iron metallogenic area

This is the second important metamorphosed sedimentary iron metallogenic area just following the Anshan-Benxi area. The proven iron ores reach up to 6.5 billion ton, accounting for 12.1% of China’s total proven iron ores. It is located in the uplift area north of North China Platform (eastern Inner Mongolia axis), and widely develops the early Precambrian metamorphic strata. The Archean metamorphic strata are well developed in this area, including the Paleoarchean, Mesoarchean and Neoarchean strata and also the Proterozone strata. Varying scales of banded siliceous iron deposits (BIF) are developed in the above different ages of Precambrian strata. The known large and super-large deposits include the Sijiyang, Chuichang, Shirenou, Mengjiagou and the recently proven Xingshan and Macheng iron deposits, and a large number of middle to small deposits are also discovered (Fig. 5).

Banded siliceous iron deposits are also developed in the early Precambrian strata in this area, and the most important ones are those in the Archean. The metamorphic degrees of iron formations are high, mostly granulite and amphibolite facies, with low amphibolite facies in few ore districts.

The presence of granulite facies iron ores and greenschist facies is the distinguishing feature of the metamorphosed sedimentary iron deposits. The ores display mainly gneissic structure, with banded structures. Magnetite has a coarse granularity, about 0.1–0.5 mm, and

![Fig. 4. Sketch showing distribution of the major iron deposits from Xichang in Sichuan Province to the middle Yunnan Province (modified from Cheng et al., 1994).](image)


is easy to do magnetic separation; some magnetite in ores of few greenschist facies rocks has fine granularity, about 0.01–0.1 mm. The ores are mainly lean ores, with iron
grade (TFe) averaging 26%–35%.

4.3.4 Iron (copper, gold) metallogenic belts in middle-lower reaches of Yangtze River

The middle and lower reaches of Yangtze River is an important iron copper (gold) mineral base in China. They belong to the lower Yangtze platform fold belt, and are located in the northeast of the Yangtze platform, near the southeastern Sino-Korean platform, belonging to a south-trending arc-shaped fault depression zone. Iron copper deposits generally distribute along the river, and begin from Daye, extending to Zhenjiang in the east (Fig. 6), and can be also observed near Haimen in Jiangsu Province. The total iron ores in this belt exceed 3 billion ton, accounting for 5.9% of the total iron ores in China, and rich iron ores have a certain proportion.

Metamorphic basement in this area is the early Precambrian Dabie and Susong groups, and equivalent middle-deep metamorphic rock series. The ore-hosted wall rocks are mainly the late Paleozoic and Triassic carbonate rock formations, and the Mesozoic volcanic rocks, subvolcanic rocks and volcano sedimentary formations.

Since the early Yanshanian period, there developed a series of faults and faulted basins on the EW-trending structures, of which the NNE-trending and NE-trending faults are deep faults. They control the main structures of the Yanshanian tectonomagmatic metallogenic belt. The junction section of the NNE-trending, NE-trending, near EW-trending and NW-trending faults are favorable for the intrusion of the Mesozoic magma, volcanic eruption and iron copper mineralization (Fig. 6).

Magmatic activities in this area are mainly intermediate-mafic to intermediate-acidic. Different ages and types of magmatite have different types and association of associated metal deposits. The skarn iron (copper, gold) deposits in southeastern Hubei Province formed earlier, and the ore-related rocks are diorite, quartz diorite, quartz monzonite and granodiorite, occurring in composite stock rock bodies. The orebodies are hosted in the contact zone between intrusive rocks and the Triassic marble. Previous isotopic data show that the rock-forming and ore-forming age ranges from 142 to 132 Ma (Xie et al., 2008; 2012). Iron deposits in the Ningwu-Luzong volcanic-hosted basins occur in the outer and inner contact zone of diorite porphyrite rockmass, and the rock-forming and ore-forming age is 131–122.9 Ma (Zhang et al., 2003; Yu et al., 2004).

Along the Yangtze River from Wuhan to Zhenjiang, the evolution of geological structures exerts a significant control on the distribution of iron copper deposits. The relative sedimentation area (Ningwu, Luzong basin) is dominated by iron ores, while relative uplift region (Tongling, Jiujian, Yangxin) is mainly copper (gold) ores. In the transitional zone between depression area and uplift area (Daye area), skarn iron (copper, gold) deposits can be observed (Zhao et al., 2004).

4.3.5 Handan-Xingtai iron metallogenic area

This is an important skarn iron metallogenic area, and is in the Handang-Xingtai area of southern Hebei Province. Tectonically, this area is in the transitional zone of Shanxi faulted uplift and North China fault depression of North
China Platform. There are total 73 different scales of iron deposits, with proven iron ores exceeding 0.8 billion ton.

The main ore-hosted wall rocks are the middle Ordovician thick limestone and dolomitic limestone, interbedded with 2–3 layers of gypsum (halite) pseudocrystal-bearing limestone. Ore-related intrusive rocks are diorite-monzonite series. The iron ore deposits mainly occur in the exocontact zone of diorite intrusions with the Ordovician limestone or dolomitic limestone, and occur as stratoid or lenticular shapes. The rock-forming and ore-forming ages are 177–121.9 Ma (Zhao et al., 2004); The Eleventh Geological Brigade of Hebei Provincial Bureau of Geology and Mineral Resources, 2010). The orebodies are closely associated with skarn, and albitization in the diorite intrusions of the endocontact zone is well developed, which can be used as an important prospecting indicator.

4.4 Ore-forming ages of iron deposits in China and evolution

The formation of China’s iron deposits ranges from the Archean to the Cenozoic, and the main ore-forming ages are the Neo-protozoic-Paleo protozoic, Hercynian and Yanshanian periods. Different iron deposit types and scales under different geological periods and conditions reflect the development of iron deposits with crustal structure evolution.

The Archean is the oldest age for the formation of metamorphosed sedimentary iron deposits in China, and a typical example is the Xingshan iron deposit hosted in the Archean Caozhuang Formation of eastern Hebei Province. The orebodies are commonly associated with high amphibolite facies of amphibolite, sillimanite biotite plagiogneis and chrome mica quartz schist to granulite facies (Shen et al., 1998). The Sm–Nd isochron age of iron seams associated with plagioclase amphibolite is 3470± Ma (Jahn et al., 1987).

Examples of the middle Archean metamorphosed sedimentary iron deposits are the Dagushan in Anshan; Shuichang, Mengjiagou, Dashihet in eastern Hebei Province; Shachang and Fengjiagou deposits in Miyun county of Beijing and Haolaiqiu in Baotou of Inner Mongolia (Shen et al., 2012). The iron orebodies are generally associated with amphibolite and gneiss of high amphibolite facies and granulite facies.

The Neoarchean-Proterozoic is the important ore-forming age for iron deposit formation in China. The metamorphosed sedimentary iron deposits in the Anshan-Benxi, eastern Hebei Province, Wutai-Luqiang, middle Inner Mongolia and Huoqiu in Anhui were mostly formed in this period, and the main forming age is the Neoarchean (2800–2500 Ma), followed by the Proterozoic (2500–
1800 Ma), with few in the Archean-Mesoproterozoic (3600–2800 Ma) (Shen, 1998; Li et al., 2011; Shen, 2012; Wan et al., 2012; Zhang et al., 2012a). This type of iron deposits occupies about 50% of the total proven iron ores in China. The Dahongshan volcanic-sedimentary iron deposit in Yunnan Province is also a product of the mineralization in the Proterozoic.

In the Mesoproterozoic, nertitic-littoral facies hematite deposits occupy an important position, mainly distributed in the settlement area near the banded iron formations (BIF) metamorphic rock series north of the North China Platform, such as the Pangjiabao iron deposit in the Xuanhua area.

The age of ore-hosted wall rocks for the Jingtieshan or metamorphosed iron deposits in Gansu is the Mesoproterozoic, and the Sm-Nd ages of the ores are 1309 Ma (Xia et al., 2001). The metamorphosed volcanic-sedimentary Huimin iron deposit in Yunnan was also formed in the Mesoproterozoic. There is considerable debate about the formation age of the Baiyunebo iron deposit in Inner Mongolia, but the main deposit should be formed at ca. 1300 Ma (Zhang et al., 2003).

The Neoproterozoic mainly formed the Xinyu type metamorphosed sedimentary iron deposits (BIF). Tang et al. (1987) suggested that, this type of deposits has stable Sinian interglacial strata, and the stratigraphical time is 680–720 Ma. During this period, few contact metasomatic hydrothermal iron deposits were also developed, such as the Lugu iron deposit in Sichuan Province. The intrusive age of the Lugu granite related with iron mineralization is 652–669 Ma (Liu et al., 1985).

Iron deposits formed in the Paleozoic have many types, dominated by sedimentary, magmatic and marine volcanic-hosted types. The sedimentary iron deposits are widely distributed in the middle-late Devonian nertitic marine sedimentary rocks series in South China, called the Ningxiang type iron deposits. Magmatic iron deposits are concentrated in the Xichang-Panzhihua rift zone of the uplift area, west of the Yangtze platform, and they occur along the deep faults, forming in the Hercynian. The latest SHRIMP age of zircons from the Panzhihua and Hongge rock bodies is 260–263 Ma (Zhou et al., 2002; 2004).

The Mesozoic era include the Indosinian and Yanshanian periods. Skarn iron polymetallic deposits were found in the Qimantage area of western Qinghai Province, such as the Galinge, Yemaquan and Kendekke deposits whose isotopic ages are 222–229.5 Ma (Feng et al., 2013; Zhao et al., 2013; Liu et al., 2013; Xiao et al., 2013), belonging to the late Indosinian period. The Yanshanian cycle is the most important tectonomagmatic activity period in China, when intermediate and intermediate-acidic intrusive rocks were widely distributed, especially in east China. These intrusive rocks are intimately associated with skarn and continental volcanic iron (polymetallic) deposits, such as the skarn iron (polymetallic) deposits in middle and lower reaches of Yangtze River, Handan-Xingtai, Middle Shandong Province, south Fujian Province-eastern Guangdong and eastern Qin Ling, and continental volcano-intrusive related iron deposits in the Ningwu-Luzong area. In the Cenozoic, iron deposits were formed in the Quaternary, dominated by weathering leaching type, followed by continental sedimentary siderite and marsh ores. In addition, there are also beach sand iron deposits, such as the sand iron deposits in the coastal areas of Taibei. These iron deposits are mostly medium-small sized.

4.5 New progress of China’s iron ore prospecting in the recent decade

Since 2004, the increasing financial supports of national fiscal and social capital on iron exploration contributed to the discovery of many hidden iron deposits through field verification of weak magnetic anomalies in east China; In western China, a large number of iron production bases and prospecting areas were discovered through enhanced prospective surveys; exploration of succeeding resources in large-medium mines resulted in newly-increased iron ores (China Geological Survey, 2008; Li et al., 2009; Zhang et al., 2011; Zhang et al., 2012a; Zhao et al., 2013).

The prospecting of the Anshan-type metamorphosed sedimentary iron deposits (BIF) and magmatic iron deposits in the northern margin and uplift area of the North China platform. The Qiaotou in Liaoning discovered thick bedded iron quartzite orebodies at depth of 1000 m, with estimated resources reaching up to 3 billion ton; In the Macheng and Xingshan in eastern Hebei Province, Yangqingshan and Zhoubei in Lingqiu of Shanxi, and Liancun in Henan Province, large-scale banded iron quartzite orebodies were discovered; hydrothermal alteration high-quality rich iron ores in the deep Gongchangling ore district of Anshan, Liaoning newly increased 70 million ton, almost doubled (Li et al., 2009; Hong et al., 2012); drilling verification of aeromagnetic anomalies in Jining of Shandong Province discovered 5–10 layers of seams at depth of 1612–1797 m, with an accumulated thickness of 100–200 m; magmatic-hydrothermal filling iron deposits in the Damiao-Heishan area of Chengde, Hebei Province newly increased many resources.

It should be mentioned that, the superlarge hidden Anshan-type iron deposits (BIF) in Qiaotou of Liaoning and Jining of Shandong have a deep burial depth (1200–1600 m depth below) and poor iron grade (26%–32% TFe). It is suggested that this type of large-scale weak
magnetic anomalies are caused by the deep-seated magnetite quartzite (BIF), which has great scientific significance but no exploitation value at present.

In the Luzong volcanic basin of Anhui with high work degree, the large Nihe hidden iron deposit was discovered in the area with weak aeromagnetic anomalies and gravity anomalies. The orebodies occur in the contact zone of the upper Jurassic pyroclastic rocks and diorite porphyrite at drill depth of 675–1096 m, with ore-intersected thickness up to 250 m; the ores have an average grade of 30% (TFe), but have a high sulfur content (22.22% S) (Wu et al., 2011). The Bajian skarn iron deposit in Shehe of Hebei Province was proven to be a large hidden rich iron deposit, and the average grade of ores is 47.56% (TFe)*.

Iron exploration in the Aulacian iron metallogenic belt of west Tian Shan, Xinjiang has discovered and explored the large- (medium) sized Chagangnuoer, Beizhan, Zhibo, Dunde and Songhu marine volcanic-hosted iron deposits, and suggested a large number of rich iron ore resources. The accumulated rich ores are 0.417 billion ton, with average iron grade of >50% (TFe) (Dong et al., 2011; Zhang et al., 2012a). Liu et al. (2009) and Yan et al. (2013) also reported that, a large number of large iron deposits were discovered in the Tashenkuergan area of west Kunlun, Xinjiang, such as the Laobing, Qiaopukalimo and Yelge deposits which occur in the Proterozoic metamorphic rock series, and are of metamorphosed sedimentary type (BIF).

In the Qimitage area of east Kunlun, Qinghai, a large number of large-medium-sized skarn iron polymetallic deposits were increasingly, such as the Galinghe, Kenkekeke and Yemaquen deposits (Feng et al., 2013; Zhao et al., 2013).

4.6 Application of minerogetic series of mineral deposits and metallogenic models in iron deposit studies and prospecting practice

The theory of Minerogetic series of mineral deposits was put forward by Cheng et al. (1979, 1983). It refers to these deposit associations of genetically related ores and genetic types hosted in different geological structures in certain geological structures and under some geological tectonic activities, related with some geological mineralization. The proposal of this theory attracted much attention and strong supports among ore geologists, and was widely cited and popularized. It transfers from studying metallogenic geological features of single deposits in the past to different types of genetically related deposit associations during certain geological periods in an area. This greatly widens the ideas of deposit studies and prospecting, and improves prospecting of iron and related metal deposits.

The establishment of metallogenic series and metallogenic models for the Ningwu porphyrite iron deposits is a good example. It illuminates various kinds of deposits formed during the overall Dawangshan volcanic cycle from eruption, subvolcanic intrusion to the late magmatic period, including the high-temperature gas-liquid metasomatic disseminated iron deposits hosted in the top of porphyrites (Taiacun type), high-temperature gas-liquid metasomatic filling veined, stocked, brecciaed and massive iron deposits (Aoshan type), contact metasomatic iron deposits (Meizishan type), bedded-stratoid iron deposits (Longqishan type), pyrite deposits (Xiangshan type) and middle-low-temperature hydrothermal veined iron deposits (Longhushan type).

From 1999 to 2004, China Geological Survey of China’s Ministry of Land Resources organized researches on regional metallogenic regularities in China and various provinces, which improves the researches on metallogenic series and its concept. A total of 214 metallogenic series of mineral deposits, 434 metallogenic subseries and 978 metallogenic models were established, and the second-generation Precambrian, Paleozoic, Mesozoic and Cenozoic metallogenic series of deposits were compiled, enhancing surveys on mineral resources (Chen et al., 2007). In the 2006–2013 national mineral resource evaluation, 71 metallogenic series (subseries) of iron deposits were divided, and thus metallogenic pedigree charts of China’s iron deposits were compiled. Li et al. (2012) systematically summarized the geological features of China’s major iron deposits and metallogenic models for each type, and this also play a role in promoting iron ore prospecting.

4.7 Innovation of iron ore prospecting methods

In eastern China with high work degree, based on metallogenic geological setting, metallogenic series and metallogenic models, a large number of large and super-large hidden iron deposits were discovered through a deep analysis of large aeromagnetic anomalies, geomagnetic anomalies and gravity anomalies, and further by bold deep drilling verification.

The Datangou aeromagnetic anomaly of Liaoning is located in the Anshan-Benxi iron ore metallogenic area. The Datangou iron deposit was discovered during verification of aeromagnetic anomalies of large survey projects of land resources in 2006. This aeromagnetic anomaly has a large scale and an oval shape, NW-trending. It was delineated by 1000 nT isolines, 8 km in its long axis and 4 km in its short axis, and the ΔT value in the central anomaly is > 4000 nT. Over the years, whether this anomaly is caused by the deep iron deposits is always unaddressed problem. The Liaoning Geological Survey
Institute verified this anomaly bolding through drilling, and finally found this superlarge hidden BIF iron deposits hosted in the Archean Anshan group. The orebodies have a burial depth of 1100–1200 m in its top, a maximum width of 1100 m and a minimum width of 650 m, and extend up to 840 m. The (333+332) iron ores are estimated to be 3.4 billion ton (Hong et al., 2010).

The Jining aeromagnetic anomaly of Shandong, located in the middle of the Cangyi mine and Dongping mine, has a super-large scale, and is 15 km in its NE length and 8 km wide; the magnetic anomalies agree with the gravity anomalies. The Shandong Geological Bureau and Shandong Geophysical and Geochemical Exploration Institute conducted an in-depth analysis on metallocgenic geological setting, magnetic and gravity anomalies to infer that, it is a NE-trending, large and deep-buried hidden iron orebodies; from 1976–2006, they implemented multiple times of deep drilling verification, and finally validated it is caused by a hidden and deep-buried superlarge BIF orebodies; at depth of 1612.89–1796.54m, a 183.65 m thick iron orebody was penetrated with estimated (334) iron resources of 12.4 billion ton (Han et al., 2008).

The large Nihe iron deposit in Lujiang of Anhui was discovered based on metallocgenic models of porphyrite iron deposits. Through systematically summarizing regional metallocgenic setting and ore-controlling geological factors, the superstition areas of 1:50000 aeromagnetic anomalies with gravity anomalies were chosen, and bold drilling verification of magnetic anomalies was conducted combined with large-scale 1:10000 geomagnetic measurements. The first hole intersected magnetic orebodies at depth of 675.78 m, with an accumulated ore-intersected thickness of 250.93m. This is a great prospecting breakthrough in deep prospecting, and is also a great discovery in the Luzong area, even in the middle-lower reaches of Yangtze River in the recent 20 years. Exploration suggests that, the Nihe iron deposits is a composite one composed of large-scale magnetite and pyrites and medium-sized anhydrite mines (Wu et al., 2011).

### 4.8.1 Metamorphosed sedimentary iron ores are the most important potential resources

Table 3 lists the accumulated proven iron ores in 17 important provinces (regions), including Liaoning, Sichuan, Hebei, Anhui, Shandong and Shanxi. The predicted iron ore resources at depth shallower than 500 m are 70.7 billion ton, accounting for 91% of China’s predicted iron ores. The proven and predicted iron ores in the most important 10 provinces (regions) are mostly metamorphosed sedimentary types, and others are skarn, magmatic and volcanic-hosted types. Metamorphosed sedimentary iron ores are mostly lean iron ores, but they have a stable ore horizon and extend greatly, making them the most prospective resources in the northern North China Platform and the inner uplift area.

### 4.8.2 Skarn iron deposits are still China’s critical prospecting targets for rich iron ores

This is because this type of deposits has a high ore grade and a wide distribution, and can be observed in 20 provinces (autonomous regions) of China. Special attention should be paid to the depth of some largemedium sized deposits and their periphery and surrounding areas.

The past exploration in China was mostly focused on the depth above 500 m, and the average exploration depth was only 392 m. The deep areas still have a large prospecting potential (China Geological Survey, 2008). The verification of the deep magnetic anomalies in the Tieshan iron deposit of Daye, Hubei in recent years led to the newly increased rich iron ores of 20.64 billion ton. The discovery of the proven large Bajian rich ore deposit is

### Table 3 Reserves and predicted reserves of iron ore deposits in major Provinces (Autonomous region) of China (100 mil. t) (after Lou, 2014)

<table>
<thead>
<tr>
<th>Province (Autonomous region)</th>
<th>Accumulated proven ore amount till 2010</th>
<th>Predicted iron ore resources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shallower than 500 m depth</td>
<td>Shallower than 1000 m depth</td>
</tr>
<tr>
<td>Liaoning</td>
<td>183</td>
<td>68</td>
</tr>
<tr>
<td>Sichuan</td>
<td>97</td>
<td>40</td>
</tr>
<tr>
<td>Hebei</td>
<td>88</td>
<td>76</td>
</tr>
<tr>
<td>Anhui</td>
<td>47.1</td>
<td>39.3</td>
</tr>
<tr>
<td>Shandong</td>
<td>47</td>
<td>11</td>
</tr>
<tr>
<td>Yunnan</td>
<td>37</td>
<td>108</td>
</tr>
<tr>
<td>Shanxi</td>
<td>34</td>
<td>35</td>
</tr>
<tr>
<td>Hubei</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>30</td>
<td>47</td>
</tr>
<tr>
<td>Hennan</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>Xinjiang</td>
<td>11.6</td>
<td>46.5</td>
</tr>
<tr>
<td>Hunan</td>
<td>11</td>
<td>44</td>
</tr>
<tr>
<td>Gansu</td>
<td>8.7</td>
<td>60.9</td>
</tr>
<tr>
<td>Guangdong</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>Jinan</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Fujian</td>
<td>6.2</td>
<td>14.8</td>
</tr>
<tr>
<td>Tibet</td>
<td>2.2</td>
<td>22.9</td>
</tr>
<tr>
<td>Total</td>
<td>661.8</td>
<td>706.4</td>
</tr>
<tr>
<td>China</td>
<td>727</td>
<td>775</td>
</tr>
</tbody>
</table>
also a good example.

In addition, in Cuoqin county of the Gangdese metallogenic belt, Tibet, the Geological Survey Institute of Jiangxi Geology and Mineral Resources Bureau discovered the Nixiong skarn iron ore mine, and the iron ores were estimated to be more than 0.1 billion ton, with iron ore grade (TFe) of 53.28% (China Geological Survey, 2008). This deposit occurs in the skarn rocks at the contact zone of the Carboniferous-Permian carbonaceous rocks with granodiorite and monzonite granites. The LA-ICP-MS U-Pb ages of zircons from granodiorite and monzonite granites are 112.6 Ma and 113.6 Ma, respectively, indicative of the relationship between mineralization and the intermediate-acidic magmatic activities in the late Yanshanian period (Yu et al., 2012).

4.8.3 A large prospecting potential of marine volcanic-hosted rich iron ores in west Tianshan of Xinjiang

As mentioned above, iron exploration in the Awulale iron metallogenic belt of western Tianshan has made great progress, and discovered a large number of large (medium) sized marine volcanic-hosted iron deposits to obtain many rich ore resources. At present, exploration work in this metallogenic belt is still continuing, and many rich ore deposits will be discovered in the near future.

Table 3 also shows that, there are still many predicted iron ore resources at depth shallower than 1000 m in Yunnan and Hubei Provinces, the former having 13.2 billion ton and the latter having 8.9 billion ton. However, iron resources which can be utilized are few, the forming have 7.2 billion ton and the intermediate having 3.4 billion ton. This is because a considerable part of the predicted iron ore resources are the Huimin type volcanic-hosted iron deposits and the Ningxiang type sedimentary deposits. These two types of iron ores have no mature ore-dressing techniques, and are difficult to utilize.

4.9 Guarantee degrees of iron resources and countermeasures

Currently, China’s production of iron ores has a low guarantee degree for iron and steel industry, less than 50%. Since the 1990s, China’s iron and steel industry has made a rapid development, but China’s production capacity of iron ores has improved slowly. This makes increasing supply gaps (Table 4), and the situation is becoming serious.

Table 4 shows a great increase of China’s steel production in the recent 23 years. It increased from 0.065 billion ton in 1990 to 0.779 billion ton in 2013, increasing by 12 times, and has occupies 48.5% of the total steel production in the world, ranking the first worldwide. During this period, domestic production of iron ores have increased greatly, but they are mostly lean iron ores and can not meet domestic steel (iron) production demand. A large number of rich iron ores are still needed to imported mainly from Australia, Brazil and India.

The static guarantee period of the world’s proven iron ore reserves can reach up to more than 100 years, and the main factors or iron ore price fluctuations a few years ago are short-term excess demands and monopoly of foreign mineral companies. Therefore, China should adhere to both independent development and foreign trade. On the one hand, we should develop independently domestic large iron mines, increase the mining capacity of iron mines and make full use of these lean iron resources which are easy to mine and dress, thus realizing the road of artificial rich iron ores. On the other hand, we should actively explore overseas mining markets, make full use of iron ore resources of the surrounding countries, and expand iron ore importing sources from multiple channels, including Afghanistan, Kyrgyzstan, Russia and Ukraine (Zhao et al., 2004; Zhao, 2009; Liu and Le, 2009; Zhang et al., 2011).

5 Conclusions

(1) The global abundant iron ore resources amount to 170 billion ton, equivalent to 80 billion ton of iron metal amount, and can guarantee at least 100 years of supply. The world’s important iron ore clusters are concentrated in Brazil, Australia, Russia, China, India, Canada, USA, Ukraine, Sweden and France, which occupy about 80% of the global iron reserves. The deposits are dominated by metamorphosed sedimentary type (BIF), followed by magmatic, volcanic-hosted and sedimentary types.

(2) China has abundant iron ore resources, and the proven iron ores amount to 84 billion ton. However, they are mostly lean, and rich iron ores only occupy 4.6% of the total China’s proven iron ores. Rich ores that can be directed put into furnace are much fewer, accounting for only 2.27%. In the proven iron ores, a considerable part

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel output</td>
<td>0.65</td>
<td>0.95</td>
<td>1.52</td>
<td>2.2</td>
<td>3.71</td>
<td>5.68</td>
<td>6.83</td>
<td>7.79</td>
</tr>
<tr>
<td>Iron ore output</td>
<td>1.79</td>
<td>2.65</td>
<td>2.17</td>
<td>2.5</td>
<td>4.10</td>
<td>8.80</td>
<td>13.3</td>
<td>14.5</td>
</tr>
<tr>
<td>Output of rich iron ore</td>
<td>0.14</td>
<td>0.41</td>
<td>0.92</td>
<td>1.5</td>
<td>2.75</td>
<td>6.28</td>
<td>6.86</td>
<td>8.19</td>
</tr>
</tbody>
</table>

Note: Some data are from Zhao (2004, 2013).
can not be utilized currently for difficult selecting and smelting, deep burial or complicated hydrological conditions. Many genetic types of the iron deposits can be observed in China, and are dominated by magmatic, volcanic-hosted, skarn, hydrothermal, metamorphosed sedimentary, sedimentary and weathering leaching types, of which the metamorphosed sedimentary type are the most important. Rich iron ores occur mainly in skarn, marine volcanic-hosted and hydrothermal iron deposit, and can also be locally observed in metamorphosed sedimentary deposits which underwent late hydrothermal alteration.

(3) The widely distributed iron deposits in China always occur in groups or clusters, and mainly concentrated in Anshan-Benxi, Xichang-middle Yunnan, eastern Hebei Province-Miyun county in Beijing, Wutai-LiLiang, middle-lower reaches of Yangtze River, Baotou-Baiyunebo, Handan-Xingtai, middle Shandong Province, Huoqiu, western Hubei Province-northwestern Hunan Province and east-west Tian Shan, which account for 80% of the China's total proven iron ores. Iron deposits formed in a wide time range from the Archeon to the Cenozoic, but the main ore-forming ages are the Neoproterozoic-Paleoproterozoic, Hercynian and Yanshanian periods. Different types and scales of iron deposits formed in different geological periods and under different geological conditions, indicative of an evolutionary characteristic of iron deposits with crustal structures. The theory of mineragenetic series of deposits and metallogenic model has been widely used in iron ore researches and prospecting, and helps prospecting greatly. A combination of in-depth analysis of acromagnetic (geomagnetic) anomalies with gravity anomalies, and bold drilling verification are an effective way for prospecting large-scale hidden iron deposits.

(4) Evaluation of resource potential suggests that, China has good iron ore prospect and a large prospecting potential. A preliminary estimation indicates that, the predicted iron ore resources at depth shallower than 500 m are 77.5 billion ton, and those shallower than 1000 m are 12.8 billion ton. However, these reserves are only roughly estimated by ore-controlling geological condition, geophysical and geochemical data. We should not be optimistic blindly, and a considerable part in-between can not be utilized for some reasons. At present, China's production of iron ores has a low guarantee degree for the iron and steel industry, less than 50%. Thus, China imports a large number of iron ores from Australia, Brazil and India annually. The international iron ore prices are mainly controlled by the foreign mining giants. Therefore, China must adhere to both independent development and opening foreign mining markets.

Acknowledgments

This study was financially supported by the National Natural Science Foundation of China (grant No. 40773038, the Program of High-level Geological Talents (201309) and Youth Geological Talents (201112) of the China Geological Survey. We thank Professor Hao Ziguo for his suggestions on writing this paper. Comments by three anonymous reviewers are also important in improving the final presentation of this work.

Manuscript received Sept. 21, 2014 accepted Nov. 20, 2014 edited by Hao Qingqing

Notes


References


Klein, C., 2005. Some Precambrian banded iron formations (BIFs) from around the world: Their age, geologic setting, mineralogy, metamorphism, geochemistry, and origin. American Mineralogist, 90(10): 1473–1499.


Ramanadou, E., Nahon, D., and Decarreau, A., 1996. Hematite and goethite from duricrusts developed by lateritic chemical weathering of Precambrian banded iron formations, Minas Gerais, Brazil. Clays and Clay Minerals, 44: 31–44.


**About the first author**

ZHIAO Yiming, Male, born in 1934 in Zhejiang Province. He graduated from Dnepropetrovsk Mining Institute (Geological Faculty), USSR in 1959 as a Geological Engineer of USSR. Now he is a research fellow of Economic Geology, and has published many papers in “Ore Geology Reviews”, “Resource Geology” and “Acta Geologica Sinica”.

Address: Institute of Mineral Resources, CAGS, Baiwanzhuang Road 26.

E-mail: zhaoyim8087@sina.com.