Chapter 1

The Chinese Iron Ore Deposits and Ore Production

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.76729

Abstract

Probably due to large national land area and multi-period orogeny, from the view of metallogeny, lots of iron deposits developed in China, and the proven total reserves of iron ores are relatively abundant, but mainly low-grade ores. For years, China's iron ore reserves are far from being able to meet the requirement of rapid development of steel industry. China is the world's largest importer of iron ore, whose imports accounted for one-third of the world's total in recent decades; however, the buyer has not the final say. The strategic importance of iron ore resources in national economy not only depends on the social value and economic value created by the iron ore exploitation, but also depends on whether the requirements of the steel industry and steel downstream industry, and safety ensuring, economy and sustainability of steel and steel downstream industry. Herein, the iron mineral processing and metallurgy technology are also briefly illustrated.

Keywords: iron ore deposits, mineral processing, ore metallurgy, iron ore demand and supply, iron ore metallogeny, China

1. Introduction

This chapter will give a general description on the Chinese iron ore deposits, supply and demand market, mineral processing and iron ore metallurgy technology. For years, the Chinese iron industry is highly dependent on the foreign mines due its quick development on economics. Presently, it is the world's largest importer of iron ore, whose imports accounted for one-third of the world's total. In fact, it holds abundant iron resource, although most are low grade and small. Therefore, the mineral processing and metallurgy technology quickly develop accompanying its iron demand and economic soaring.

2. China's major iron ore types

Probably due to large national land area and multi-period orogeny, lots of iron deposits developed in China, and the proven total reserves of iron ores are relatively abundant, but mainly low-grade ores. The research shows that the types of iron ore deposits in China are diverse and the metallogenic epoch spanned from the Archean to the Cenozoic, which mainly includes seven types [1–6].

2.1. Sedimentary - metamorphic iron ore deposits

This type of iron deposits is also called banded iron formation (BIF). The mineralization ages were mainly Archean and Paleoproterozoic. The reserves of proven mineral resources were probably more than 33 billion tons, accounting for 55% of the total reserves of the country, which is a very important iron ore in China. According to the ore and gouge mineral association, as well as geological features, it would be subdivided into metamorphic iron-siliceous iron ore deposits and metamorphic carbonate iron ore deposits. Their grades were about 25–40% (w(TFe)).

The BIF were affected by regional metamorphism and associated with volcanic-iron-siliceous sedimentary deposits. They mainly developed in the Precambrian metamorphic rocks, mostly large deposits. The Anshan in Liaoning Province, Jidong in Hebei Province, Wutai-Lvliang in Shanxi Province, and central Inner Mongolia are mainly developed area where the iron ore deposits were thought the most representative. The southern margin of Yangtze plate, Qinling orogenic belt, Qilian orogenic belt, and the East Tianshan region were also distributed.

The metamorphic carbonate iron deposits were carbonate-type sedimentary iron deposits suffered to minor regional metamorphism. They mainly developed in the Proterozoic strata, and the southeast Jilin Province is known for yielding this deposit. That led to it also called "Dalizi type iron ore deposit" in China, although it is also developed in Yimen, Eshan, Huanian in Yunnan Province.

2.2. Late magmatic iron ore deposits

This type of iron ore deposit is associated with the mafic-ultramafic magmatic intrusions of the iron and its iron minerals are rich in vanadium and titanium, commonly referred to as vanadium-titanium magnetite deposits. The mineralization ages are mainly Paleozoic and Proterozoic, with proven reserves of 9 billion tons, accounting for 15% of the total reserves of the country. According to the metallogensis, they can be subdivided into late magmatic differentiated deposits and late magmatic intrusive iron deposits. Late magmatic differentiated iron deposits are formed by the residual magma rich in iron, vanadium and titanium formed by late differentiation of magma crystals. These deposits are mostly of large in reserve and are mainly distributed in Panzhihua and Xichang area in Sichuan Province. They are often called "Panzhihua-type" iron deposits in China. Late magmatic intrusive iron deposits are late-differentiated iron-bearing ore fluids that break into or along the rock mass. The reserve of this

http://dx.doi.org/10.5772/intechopen.76729

type deposit is generally medium to small, mainly distributed in the Damiao and Heishan in Hebei Province, which is called the "Damiao-type" iron deposit.

2.3. Contact metasomatic - hydrothermal iron ore deposits

This type of iron ores are associated with the contact metasomatism resulted from intrusive rocks and carbonate rocks, and are formed by the exchange of iron-bearing gas-water solutions. Such deposits generally have typical skarn mineral assemblages and are also known as silicon carbon type deposit. Skarn iron ore ages were mainly Mesozoic, ore grade is generally rich, the reserves are generally small and medium, although there are some large ones. Identified reserves of this type are 8 billion tons, accounting for 13% of the total reserves. Skarn iron ore is widely distributed in China, with such deposits as Handan, Laiwu, Daye and Linfen in the east. In addition, Cuihongshan in Heilongjiang Province, Huanggang in Inner Mongolia, Lizhu in Zhejiang Province, Dading in Guangdong Province, Mulonggou in Xianxi Province and Nixon in Tibet also yield skarn type iron ore deposits.

2.4. Volcanic - intrusive type iron ore deposits

This type of deposit is associated with volcanic rocks and sub-volcanic rocks in a genetic relationship, with a proven reserve of 2 billion tons, accounting for 4% of the country's total reserves. It would be divided into continental volcano-intrusive iron ore and marine volcano-intrusive iron deposits.

Continental volcanic-intrusive iron ore deposits are mostly associated with middle- or medium-acid volcanic rocks and are mainly produced in volcanic clasts or in the contact zones within and around the pluton. The mineralization age is Mesozoic. It is mainly located in Ningwu-Luzong area, often referred to as "porphyrite iron ore". In addition, the Jiaduoling iron ore deposit in Tibet and the Liangzi iron ore in Sichuan Province are also known as continental volcano-intrusive iron deposits.

2.5. Sedimentary iron ore deposits

This type of deposits was formed by weathering, then broken, decomposed, transported of iron-bearing rock to low-lying basins, and after mechanical deposition, or some through the deposition of differentiation. Metallogenic times of sedimentary iron deposits are diverse with a proven mineral resource of 5 billion tons, accounting for 9% of China's total reserves. According to the sedimentary environment, there are two subtypes of this kind: marine type and lake facies type. Marine sedimentary iron deposits were produced in various geologic periods after Neoproterozoic. It is represented by "Xuanlong" iron ore of Pangjiabao and the "Ningxiang" iron ore Ningxiang in Hebei Province.

2.6. Weathered leaching type iron ore deposits

These deposits are formed by weathering and leaching of the rich iron rocks and/or iron-bearing polymetallic ores, and iron ore was accumulated on the residual slope. This type is shallow and mainly of middle and small in reserve. They are mainly distributed in Guangdong, Guangxi, Fujian, Guizhou and Jiangxi Provinces. The reserves of proven deposits are 300 million tons, accounting for 0.5% of the total reserves of the country.

2.7. Others

This includes mainly two deposits: the Bayan Obo and Shilu in Inner Mongolia and Hainan, respectively.

The Bayan Obo deposit is a world famous super-large iron-niobium-rare earth deposit with extremely rich minerals and elemental assemblages. However, due to the complexity of the iron deposit, there is no unified view on the origin of this deposit. Most believe that the formation and original deposition of iron ore associated with later hydrothermal fluid alteration, which means the iron ore was enriched by alteration on the primary ores. The mineral composition of the Bayan Obo mine is extremely complex. A total of 71 elements have been discovered and the mineral species have reached more than 170 species. There are five major ore bodies, with the iron deposits mainly occurring in the 8th member of the Bayan Obo Group. Proven reserves reach 1.6 billion tons [7–10].

Shilu iron deposit in Hainan Province was hailed as "Asia's largest iron ore rich", and ore mineral is mainly hematite, associated with cobalt, copper and nickel. At present, there is no unified understanding of the ore-forming mechanism of Shilu iron ore deposit. Some argued that formation of Shilu iron ore is mainly due to multiple remodeling and enrichment that is, the formation of iron ore deposits is affected by "volcano-sedimentary metamorphism + structural transformation + hydrothermal". A total of 38 iron ore bodies have been found, most of which are yielded in the 6th layer of Shilu Group. The proven iron ore reserve has exceeded 450 million tons and the grade is high (the average grade of iron ore is 51%) [11, 14, 15].

2.8. Comparison of major iron ore deposits from domestic and abroad

Iron ore resources are distributed in a few countries and regions with high concentration. 75.6% of the world's iron ore reserves are distributed in Russia, Ukraine, Australia, Brazil, Kazakhstan and China. In general, there are more iron-rich mines in the southern hemisphere and less in the northern hemisphere [12]. Among the top 100 iron ore production projects in the world [13], 76 are related to BIF and the output of these 76 BIF-related iron ore projects also accounts for 87% of the world's iron ore production (**Figure 1**). The giant iron deposits in China are all BIF type and were yielded in craton. The largest one hosted about 4 billion tons of iron and was formed in Middle Archeozoic. However, it was low grade, whereas to the giant iron deposits abroad, they are various from skarn-related type, Kiruna type or magmatic type for the metallogeny. Besides, they are not restricted to Precambrian. For the tectonic background, they could develop on craton, as well as on active continental margin.

Among more than 2000 iron ore deposits identified, the contact metasomatic-hydrothermal iron deposits account for 39% of the total iron ore deposits, followed by sedimentary metamorphism (28%) and sedimentary (20%), weathered leaching (7%), volcanic (3%) and magmatic (3%) iron ore are in small numbers. However, most of the large iron deposits are characterized by

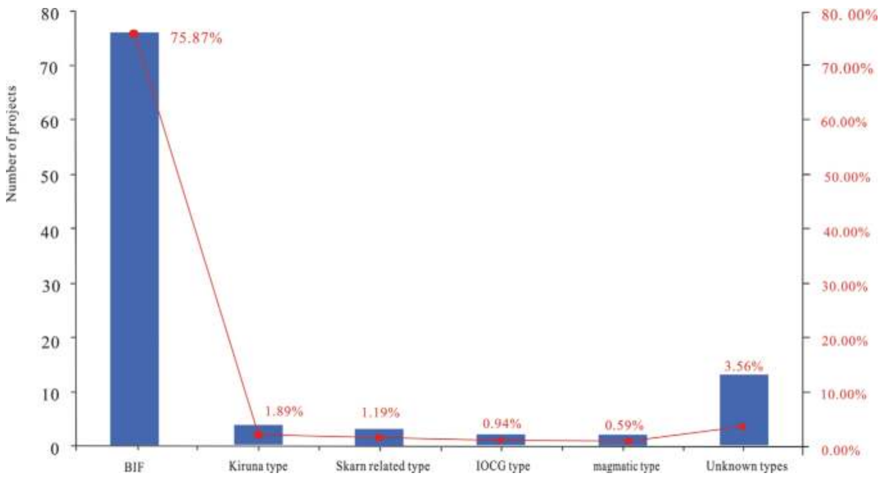

Figure 1. World's top 100 iron ore production projects with different metallogeny and the global proportion of iron ore production of various types.

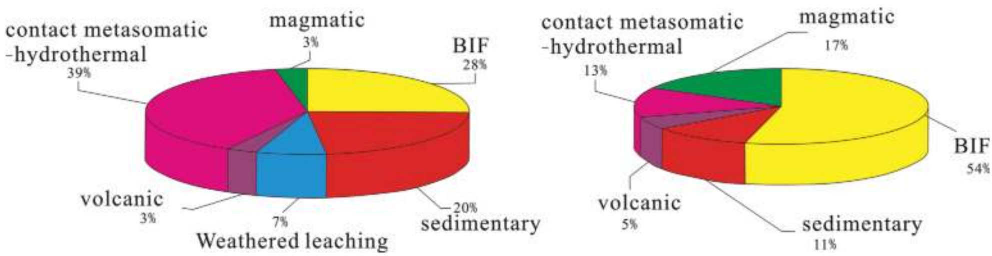

Figure 2. The proportion of different types of iron ore for metallogeny (A) and the proportion of large ones of all six iron ore deposit types (B) in China [4].

sedimentary metamorphism type, accounting for 54% of the total number; followed by magmatic type, accounting for 17%; and the contact metasomatism-hydrothermal iron deposits are dominated by small and medium-sized, while the large ones accounting for only 13%; weathered leaching type do not yield large iron ore deposits (**Figure 2**).

3. Iron ore supply and demand in China

China's iron ore sources are mainly three parts, the first part from the domestic ore, the second part from the overseas rights and interests of ore and the third part from overseas imports of ore. From 2011 to 2015, the proven reserves of iron ore continued to increase. In 2015, the reserves of iron ore reached 20.76 billion tons (note: different from the US Geological Survey released 2015 reserves data, it is mainly caused by different iron ore units of measurement), a slight increase of 0.50% year-on-year. Since 2015, China's iron ore production has gradually declined. In 2016, China's iron ore production (including low grades) was 1.281 billion tons, down 7.27% year-on-year.

3.1. Domestic ore production analysis

As China's crude steel production for many years running high, and more than 90% of the output is made of iron ore as a raw material contribution, resulting in huge demand for iron ore. While importing a large amount of iron ore, the output of China made iron ore is rapidly growing. Before 2000, China's iron ore output has been stable at an annual of less than 200 million tons (**Figure 3**). The output has continued to increase rapidly since 2001, with an annual output of 590 million tons in 2006 and a record high growth rate of 38%. During 2007–2009, China's iron ore demand was strong and the supply of oversea deposits increased more rapidly. Although the total output amount of domestic mines continued to increase, its growth rate slightly decreased from the previous period. In 2010–2011, due to the 4 trillion yuan investment stimulating steel consumption in China and the rapid growth of international iron ore prices, historical records have been continuously refreshed. Many low-grade deposits, previously considered non-economic for mining, have also been gradually exploited. Domestic iron ore in 2011 reached 1.32 billion tons, an increase of 27%. After 2012, the growth of China's economy slowed significantly; however, the supply of oversea deposits continued to accelerate. Therefore the demand exceeds supply was gradually reversed. As a result, the price gradually dropped and the domestic high-cost mines were gradually squeezed out of the market. In 2012–2014, the growth rate of output of domestic iron ore decreased rapidly, and the output of in 2014 was 151,000 tons, an increase of 3.9%, although it slightly increased in 2016. In the past 16 years, China's domestic iron ore production increased 7.4 times, an average

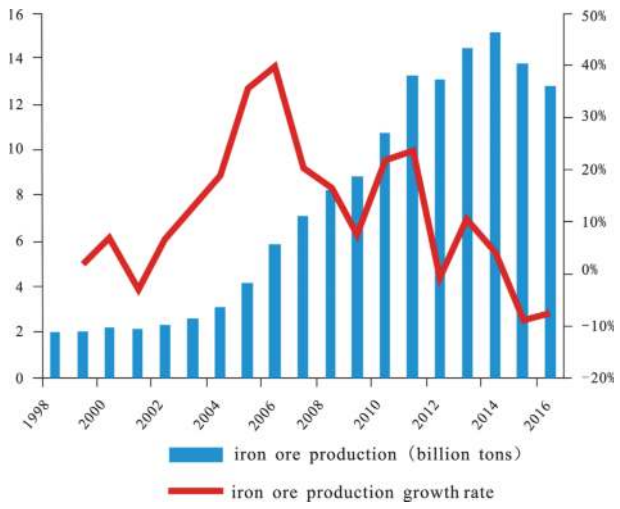

Figure 3. Domestic iron ore production and growth rate.

annual growth rate of 14.6%, and domestic iron ore is an important part of China's steel production of raw materials.

3.2. Analysis on iron ore import

Between 2003 and 2017, the average annual growth rate of China's iron ore output was about 18%. Meanwhile, the average annual growth rate of imported iron ore was 20%. The growth rate of imports was obviously higher than that of self-produced ore. Since 2000, China's iron ore imports, except a slight decrease in 2010, 2012 and 2015, increased substantially, the annual import grew twice over 35%.

By 2000, the major steel-making countries accounted for a relatively large amount of global imports. For example, Japan, the country with the largest import tonnage, accounted for an annual average of 28% in the world (**Figure 4**). Since 2000, due to the rise of China, the world's iron ore import pattern has undergone dramatic changes. China surpassed Japan in 2003 to become the world's largest importer of iron ore. The proportion of South Korea, Germany and Taiwan of China decreased slightly but little changed. The proportion of Japan was smaller; however, it is still the second largest iron ore importer in the world. In 2014, China imported 922 million tons of iron ore, accounting for 48% of the global output, 64.3% of the world's total iron ore imports and more than 70% of the global iron ore seaborne volume, and contributing to more than 90% of global iron ore consumption. In 2017, China's iron ore imports increased to 1.075 billion tons, which is 14 times of 2000. China is the world's most important iron ore consumer market and the world's largest spot market for iron ore. At this stage of relatively stable demand in Japan, South Korea, Germany and Taiwan of China, the proportion of imports from other countries is too small and China imports huge amount of iron ore, the changes in the demand for imported iron ore in China's iron ore market can approximately reflect the changes in the global iron ore spot market.

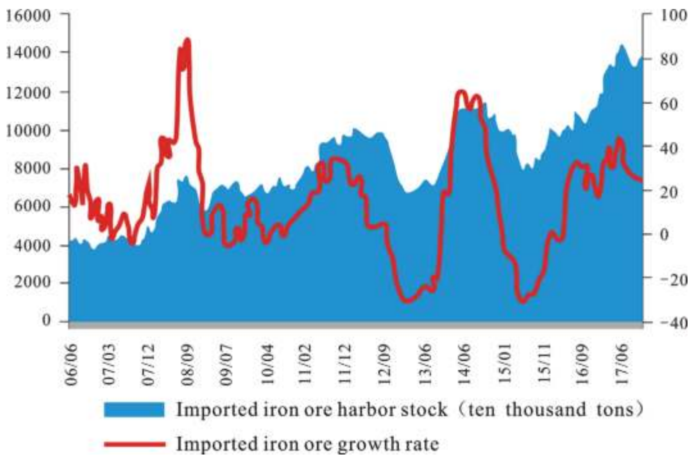

Figure 4. Iron ore imports/growth rate.

3.3. Investment development on overseas rights and interest mines

China's iron ore resources development of "going global" has 30 years of history. In 1987, Sinosteel Australia Limited and Australia's Morris Iron Ore Co., Ltd. formed a contractual joint venture to jointly develop and operate Chana Iron Mine, making it the first overseas iron ore investment project. A total investment of 200 million US dollars, officially put into operation in 1990, iron ore production in 2011 reached 11 million tons. Due to the still low domestic demand at that time, the increase rate of overseas investment and mine development was relatively slow. In recent years, due to the sharp increase of iron ore demand, the scale of overseas investment in iron ore in China began to gradually expand [14–16]. From 2006 to 2017, the investment in the rights and interests of overseas iron mines of various types of enterprises totaled more than 30 billion dollars and participated in the exploration, design and construction of more than 40 large-scale overseas iron ore projects [17].

China's overseas investment in iron ore is mainly concentrated in Western Australia, Quebec of Canada, Brazil, Mongolia and West Africa (**Figure 5**). Among them, there are 19 cooperation projects in Australia with high grade and abundant resources of iron ore, accounting for almost half of all overseas projects [17]. Canada mainly includes five projects of Wuhan Iron and Steel Group Company. There are three projects in West Africa, mainly in Guinea where invested 20 billion yuan, conducted by the Aluminum corporation of China. Due to differences in infrastructure investment, labor costs and resource conditions, the cost of projects invested in West Africa is lower than that in Australia. Up to 2013, China's overseas rights and interests iron ore production capacity of 73 million tons, accounting for about 10% of iron ore imports. However, compared with Japan's overseas rights and interests iron ore production capacity of 74 million tons, accounting for 57–70% of its annual import of iron ore, the gap between China and Japan is too large [17].

The global high-quality resources of iron ore have all been controlled by four enterprises. Oversea investment is high cost. As iron ore prices soared, Chinese enterprises have gone out to prospecting. When the spot price is as high as 130–180 US dollars/ton, the average mining cost can be sufficient for 100 US dollars. Based on this, mining enterprises go out to buy the

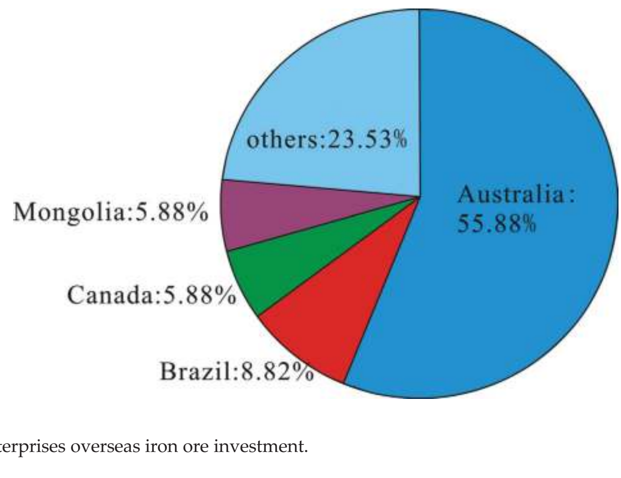

Figure 5. Chinese enterprises overseas iron ore investment.

rights and interests of the cost of the current spot price are very high. According to public information, it is learned that in recent years, the minimum cost for China to go overseas to acquire iron ore right and interests is the iron ore project in Liberia of WISCO, accounting for about 70 US dollars/ton at that time. However, due to the drastic drop of iron ore prices since 2014, up to the beginning of November 2015, the domestic spot price of iron ore has dropped below 50 USD/ton. For the 2 years 2014–2015, the development cost of overseas rights and interests mines are almost totally higher than the spot price, and the volume of iron ore shipped back to the China will inevitably decrease drastically. The high cost of mining, coupled with the cost of repatriation, is completely unmanageable compared to the spot price of $50–40/ton.

3.4. Problems existing in China iron ore supply

3.4.1. The actual supply of domestic ore is insufficient

Due to the continuous high output of crude steel in China for many years and the fact that more than 90% of the output is contributed by iron ore (long-flow steel), the demand for iron ore is huge. The output of domestic iron ore increased rapidly, with a compound annual growth rate of about 14%. In terms of quantity, the output of domestic ore is much higher than that of imports. Although the growth of China's own-produced iron ore is rapid, it has been found in actual research that the actual growth of China's domestic iron ore production is much lower than the statistic data. In the statistics data on iron ore production, there is no distinction between finished ore and raw ore, the low grade of raw ore without treatment was put directly into the statistics data, resulting in a sharp rise in China's domestic iron ore output data. In recent years, due to soaring iron ore prices, low grade of 10% of the iron ore is exploited; at the same time, these low grade ore will inevitably push up China iron ore production data.

After iron balance rebound calculation, China made only 210 million tons of domestic finished iron ore in 2014. It is far from 1.5 billion tons which is from statistics data. The self-sufficiency rate of iron ore dropped from nearly 60% in 2002 to a nearly straight decline. The huge contrast between country-made ore and those data of the after iron balance rebound calculation means that the supply of domestic ore is approaching the end of its growth.

3.4.2. Foreign iron ore dependence is too high

Although the total reserves of iron ore resources in China are huge, the distribution of iron ore resources is more dispersed, with more lean mines, very few rich mines, and mostly polymetallic iron mines. The ores are difficult to mine, the cost of mining is high, and the actual output cannot meet the production needs of domestic steel mills, therefore domestic steel producers have to choose to import large quantities of iron ore. Since 2000, China's iron ore imports have risen sharply, except a few years. The annual import growth rate once exceeded 40% twice.

With the rapid increase in iron ore imports, there is also a growing dependence on foreign iron ore (**Figure 6**). From only 36% in 2002, China's iron ore dependence on foreign countries has risen to more than 87% in 2016. In the coming years, the imported iron ore will remain at a high level. With the further price drop of imported iron ore, the domestic mines will be discontinued and the scope of bankruptcy will continue to expand. The import volume will continue to increase. The dependence on foreign iron ore will be over 90%.

3.4.3. Iron ore import source is too concentrated

China's imports of iron ore are mainly iron ore powder, massive iron ore (raw ore) and pellets, respectively, from more than 30 countries and regions, in which Australia, Brazil, India and South Africa are China's most important source of iron ore imports. The imports from the four countries accounted for about 85% (**Figure 7**). To protect its iron ore resources, the Indian government gives priority to ensuring its domestic steel production needs. Since 2011, the Indian government has increased export tariffs on iron ores and restricted exports. In recent years, the number of imported iron ore from India has been declining year by year. CVRD (Companhia

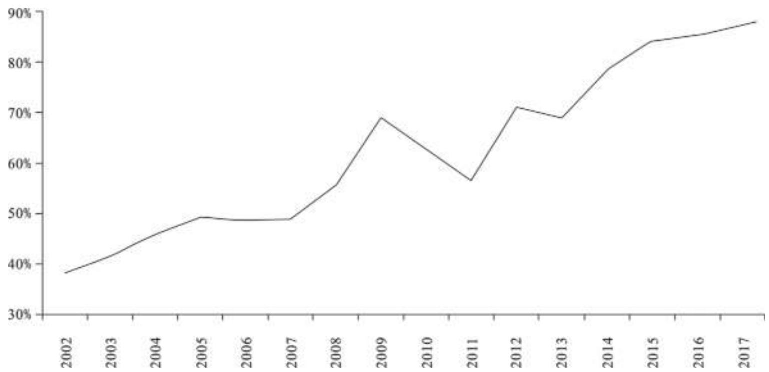

Figure 6. China iron ore dependence on foreign countries.

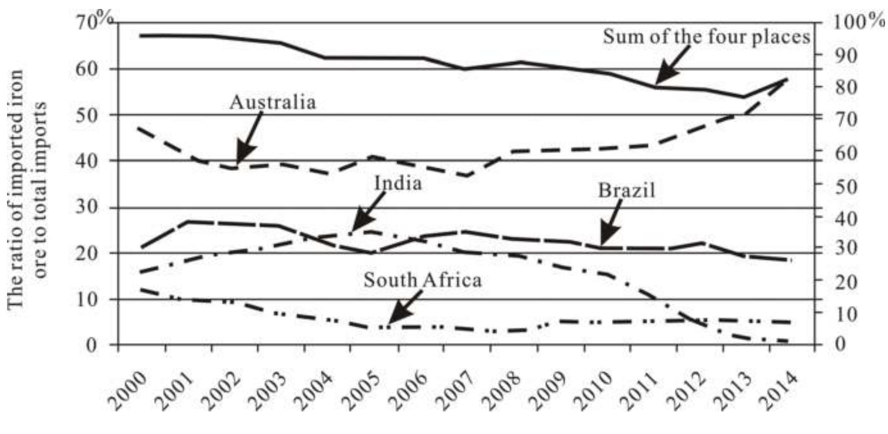

Figure 7. China iron ore import country analysis (left axis account for Australia, India, Brazil South Africa of the total import volume, and right axis account for sum of the four places mentioned above for the total import volume of the whole China).

Vale do Rio Doce in Brazil) is one of the main channels for China's iron ore imports, accounting for an average annual import volume of about 23%, but its proportion has dropped to 18% due to the substantial increase in the supply of iron ore from Australia in 2016 and 2017. South Africa's imports were relatively small, accounting for about 6% of the total. Australia is the most important source of iron ore. The average annual import volume accounted for 44%. Due to economies of scale and the efficiency gains for mining companies, the mining cost was getting down. Rio Tinto said publicly in 2014 that the cost of mining had fallen to less than $18/ton. Therefore, China's total imported iron ore from Australia is likely to continue to increase.

Now that iron ore is no longer a simple mean of production, its financial properties are gradually appearing. The major mines have been firmly controlled by financial capital (**Figure 8**). After understanding the global iron ore production costs, it is possible to speculate on the soaring of iron ore prices in previous years that the huge financial capital behind it is the most important promoter. At the present stage where the political situation is relatively stable, the main risk of over-concentration of import sources is the manipulation of iron ore prices stemming from the financial capital giants behind the mines. If the political situation in the future changes suddenly and the relevant governments at the source of imports restrict the export of iron ore to China, the steel industry will also face a nastier situation, which will in turn affect the social stability.

3.4.4. Iron ore prices fluctuated sharply

Before 2002, iron ore was the absolute buyer's market. In order to facilitate the purchase of Chinese enterprises, the three major companies (Rio Tinto, BHP Billiton and Companhia Vale do Rio Doce) at that time even gave a rebate, and the price of iron ore has been relatively low. However, with the rapid economic growth in China, the continuous expansion of production capacity in the iron and steel industry directly led to the soaring iron ore prices (**Figure 9**). Due to the fact that many Chinese small and medium iron and steel enterprises are not eligible for long-term agreement price, their huge demand has pushed up the price of spot market. From 2007 to 2013, demand growth was too fast, iron ore was in short supply and prices rose sharply. After 2014, due to the newly increased output of iron ore put into operation by the

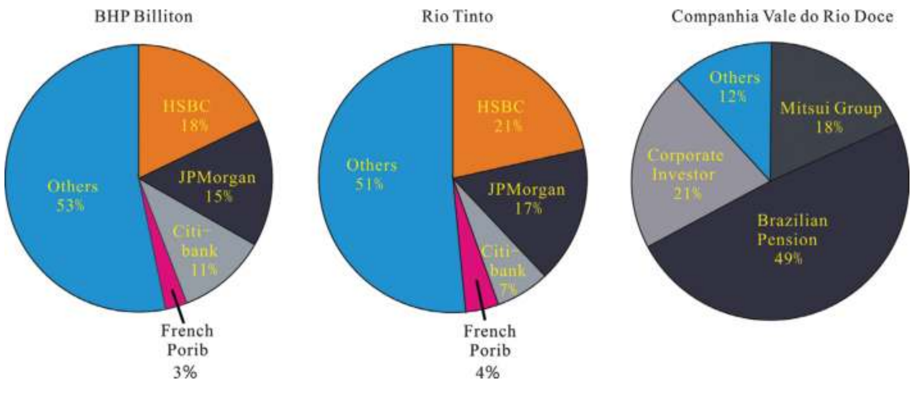

Figure 8. Rio Tinto, BHP Billiton, and Companhia Vale do Rio Doce financial capital structure.

Figure 9. Japan's Shinkansen iron ore price index.

global mining enterprises in 2014–2015, the supply of iron ore will be oversupplied. Iron ore prices fell for 4 consecutive years, until 2016, however, from 2016, it reversed again. It rose slightly (**Figure 9**). Over the past 10 years, iron ore prices have experienced two rounds of highs and lows, and the highest point has surpassed 180 US dollars/ton, while the lows have already broken through 50 US dollars/ton.

3.4.5. Obtaining overseas rights and interests mines is difficult

Iron ore resources in any country belong to the strategic mineral resources, with the interests of nations, in any country are highly concerned about. With the economic development and social construction of third world countries, the demand for iron and steel resources will inevitably increase the demand for iron ore resources. In the future, the emerging economies in the world will compete for iron ore resources more intensively. The high grade and large reserve mines are occupied by the international mining giants. Besides, international mining giants relying on their strong business base for many years, still in the form of acquisitions, mergers and other forms of global search for high-quality iron ore resources, are still constantly expanding their sphere of influence. China's steel enterprises that want to get high-quality mines are very difficult. They missed best time to purchase high-quality mines oversea. In addition, Japanese consortium set malicious difficulties to them. China's steel mills have paid a huge price for this. It mainly include: (A) the acquisition cost is too high. Currently, the average grade of overseas iron ore resource invested by the Chinese side is about 40%. Although its quality is inferior to that of the United States, Europe and Japan, it is still superior to the domestic iron ore [14]. Overseas mines geographical locations are mostly terrible, need to increase a large number of mineral processing, power plants, water and other facilities investment in construction, development and construction costs will inevitably increase [14]. According to the current investment in projects under construction estimates, the first phase of overseas iron ore development projects to build capacity of 10 million tons of investment is about 2 billion US dollars on average; if it is a low grade one, the investment will require nearly 3 billion US dollars, such as the Guinea project, the total investment of the project has now reached as high as 20 billion U.S. dollars [17]. In fact, most overseas iron ore projects cost more than US $100/ton. (B) Large stake, high risk, hard to quit. Chinese enterprises target for the leading enterprises or the top few companies. Most of these large-scale overseas investment enterprises are state-owned. Because their management does not make money for the purpose of their business, but rather their personal performance as the starting point, they just want to make big achievements, win media acclaim and earn their personal social reputation, resulting in state-owned enterprises inefficiency and the investment frequently failed. For example, Shougang group tried to buy most of all stock right of a Peru company, Aluminum Corporation of China bought Rio Tinto and China Minemetals Corporation bought OZ. In certain sense, all failed. This may give the absolute control over the acquisition of the business, but at the same time will inevitably increase the operational burden. This type of large investment, which concerns only one company, will weaken the risk-resist capability greatly. Once a sharp decline in ore prices, lower profitability, or even loss, companies will be difficult to quit smoothly. Japanese did the opposite. Instead of pursuing the holding of the other side's enterprises, they hold mostly 10% or even lower of the stock of target company. In addition, they did not choose the big ones. The manager of the Japanese company did not seek reputation. Japanese businessmen aim at maximizing business profits, and their business decisions are based on costs and benefits. For example, Mitsui & Co., Nippon Steel and Sumitomo Metal jointly owned Robe River Company of Australian, and then supported the expansion of the company, which indirectly press Rio Tinto and BHP Billiton.

Compared with Japan, China's overseas iron ore investment started recently, and is still in the learning stage, compared with Japan's investment efficiency and return on investment is still a big gap. Chinese enterprises and the Chinese government still urgently need to learn from Japan on the concept of iron ore overseas investment, management experience and risk prevention.

4. Mineral processing and ore metallurgy technology

In order to improve the self-sufficiency rate of iron ore and get rid of the shackles of foreign mining giants, a great deal of research work has been carried out by relevant researchers around the efficient utilization of iron ore resources.

4.1. Fine grain iron ore beneficiation

In China, iron ore with hematite grain size of less than 0.045 mm or magnetite grain size of less than 0.03 mm is commonly referred to as fine-grained iron ore [18]. Yuanjiacun Iron deposit and Qidong Iron deposit in Shanxi and Hunan Province, respectively, are the most typical fine grain iron deposits in China. The Taiyuan Iron and Steel Group and scientific research units, who aimed at the Yuanjiacun iron ore recycle and conduct a large number of experimental studies. The original iron ore grade of 31.18%, −0.045 mm particle size accounted for 93.81% of the total ore, they got concentrate iron grade 66.95%, and recovery rate of 72.62%. With this process, the Yuanjiacun iron deposit built a mineral processing plant with annual capacity of

22 million tons by the end of 2012 [19]. Changsha Institute of Mining and Metallurgy proposed a selective flocculation desliming-anti-flotation technology and developed a SA-2 flocculant (for the purpose of fine grain size, complex nature of igneous iron ore in Qidong iron deposit) [20]. At present, the Qidong iron deposit uses this technology to build a beneficiation plant with an annual treatment capacity of 2.8 million tons. Under the conditions of a raw ore grade of 28.36% and a grinding fineness of −0.038 mm (98%), the concentrate iron grade 62.5%, the recovery of 68% have been achieved [18–20]. There are many examples like this. Stage grinding —stage magnetic separation likely is the best process for processing fine-grained magnetite [21, 22]; for fine-grained magnetite-hematite mixed iron ore, weak magnetic—strong magnetic—resurfacing—reverse flotation process can obtain the high recovery rate; that sorting fine particles hematite process mainly has strong magnetic—desliming—reverse flotation [23, 24], selective flocculation—reverse flotation [25] and strong magnetic—centrifugal beneficiation [26].

4.2. Efficient grinding technology

It would be subdivided into: high-pressure roller mill technology, self-grinding/semi-self-grinding technology and stirring mill technology [12]. The high-pressure roller mill technology is highly dependent on ore ultra-fine grinding equipment: high-pressure roller mill. It is a unit of low energy consumption, high handling capacity. Compared with the traditional crushing equipment, high-pressure roller mill pulverized products significantly increase the internal microcracking, ensure high content of fine-grained fraction and mineral dissociation [3, 27–30]. Domestic experts and scholars carried out a great deal of research work on the application of high-pressure roller mill technology in iron ore, and formed the crushing-preselection technology of high-pressure roller mill to maximize the crushing and minimize friction in order to reduce processing costs. Masteel company conducted this technic on low-grade iron ore (including high-pressure roller mill, wet grading, coarse magnetic separation pre-selected tail-polishing technology) in Nanshan iron ore deposit, the annual throughput of the beneficiation plant increased by 2.7 million tons, and the electricity consumption and the consumption of steel per unit ore dropped by about 30% [20]. And then, this technology has been introduced into dozens of iron ore processing plants in Hebei Province such as Sijiaying Iron Mine, Panzhihua Iron Mine in Sichuan and Dachang Iron Mine in Anhui [31]. The grain size, grinding and dissociation characteristics of lean hematite ore after being crushed by a high-pressure roller mill have been studied. Details of this technology are still locked. However, compared with the jaw crusher, the high-pressure roller mill has a high crushing ratio, high content of fine-grained, uniform particle size distribution and the Bond power index decreased by 13.96–28.23%, −0.5 mm grain iron ore monomer dissociation increased by 15.16% [13]. Compared with the conventional three-stage closed-circuit crushing process, the self-grinding/semi-autogenous grinding process has the features of simple process, low capital investment, large-scale equipment efficiency and low dust pollution. At present, China has more than 60 beneficiation plants using more than 160 self-grinding/semi-autogenous mills. For example, Dahongshan Iron Mine of Kunming Iron and Steel Co., Ltd. has used 8.53 m × 4.32 m semiautomatic milling + ball milling + ball milling (SAC) process to crush iron ore from 2006 with the processing capacity of 4 million t/a [1]. Stir mill as a fine to ultra-fine grinding equipment was gradually being applied to the fine-graining of iron mines in China [20, 32]. In 2010, Panzhihua Iron and Steel Co., Ltd. purchased three tower mills from Ericsson of Germany for fine grinding of vanadium-titanium magnetite. In July 2013, three tower mills of Dahongshan Iron Ore from Kungang Steel were put into production. In 2013, Ansteel Mining Company purchased six sets of vertical spiral mixing mill manufactured by Metso for the Guanbaoshan Iron Ore Concentrator. Li et al. [30] explored the possibility of further improving the grade of concentrate obtained by magnetic separation at a grinding stage of a large-scale iron ore mine in Shandong Province. He began with the concentration of iron grade of 62.35% with 0.022 mm and access to iron grade greater than 65%. The comparison of mixing mill and ball mill on Shizhuyuan iron deposit, Hunan Province show that: when using a stirred mill, the content of newly formed −0.038 mm granular material is 8.1% higher than that of the ball mill, and the monomer dissociation degree of the mixed mill product is obviously higher than that of a ball mill, and the grade of the refined mill product after magnetic separation is 5.2% higher than after ball mill [33].

4.3. Magnetization roasting technology

In recent years, many domestic research units aim for magnetization roasting technology and equipment and carry out a large number of studies. Flash magnetization roasting technology was one of them, which was proposed by Yu and his team [34]. And then this technology was applied to the Daxigou siderite deposit, Wangjiatan magnetite deposit, and Jielong magnetite deposit, where they obtained iron grade more than 55 and 70% of recovery rate. In 2009, Lingbao plant started the pilot construction of flash magnetization roasting project of 50,000 tons per year. In 2012, the Institute of Process Engineering of Chinese Academy of Sciences built the pilot project of annual handling capacity of 100,000 tons of refractory iron ore fluidized roasting. Northeastern University put forward a complex refractory iron ore suspension roasting technology, and designed a laboratory batch suspension roaster. Using the designed roaster, restricted the air velocity, reducing gas concentration, calcination temperature and roasting time were tested on the positive flotation tailings and oolitic hematite of Anshan Iron & Steel Co., Ltd. at Dong'anshan Sintering Plant. Under the best experimental conditions, they got iron grade 56–61% and recovery rate of 78–84% [35]. According to the basic research results, Northeastern University and the Institute of Mineral Utilization of Chinese Academy of Geological Sciences and Shenyang XinBo Industrial Design Co., Ltd., designed and built a 150 kg/h complex refractory iron ore suspension roasting pilot system in Emeishan City. In September 2014, the continuous flotation test was carried out with the positive flotation tailings from the tailings of the East Anshan Sintering Factory and the magnetic separation of the tailings of the Ouzanshan Magnetic Puller tailings. The magnetized roasted products produced by this system, after magnetic separation, reached the grade of concentrate iron 63–65%, and the recovery rate of 78–83%.

4.4. Deep reduction and magnetic separation technology

For those beyond conventional processing methods and magnetization roasting technology, the relevant domestic researchers put forward a deep reduction-magnetic separation technology that uses coal as an agent to reduce iron ore minerals to metallic iron below the melting temperature of ore, and then promotes the growth of metal iron particles to a certain size. Deep reduction-magnetic separation technology for the development of complex refractory iron ore provides a new way to become one of the hot topics in the field of mineral processing in recent years. Raw materials of oolitic hematite, hematite with carbonate, iron tailings, red mud, Zinc-bearing iron ore were tested by this technic. After the magnetic separation, the deep reduced iron powder with 85–95% Fe and more than 90% recovery rate can be obtained [36]. Deep reduction temperature is generally higher than 1000°C, iron ore reduction process is $Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$. The process of reduction can be divided into three stages: initial, middle and late stage. The reaction kinetics models of each stage are Avrami-Erofeev equation, chemical reaction model and three-dimensional diffusion model, respectively. The size of the iron particles in the reduced material can be detected using optical microscopic image analysis techniques. It is noteworthy that the reduction temperature and the reduction time have a significant effect on the size distribution of iron particles [21].

High-phosphorus oolitic hematite is an important iron ore resource in China. Due to the extremely fine grain size (less than 10 μm) and high-phosphorus content of hematite, it is difficult to effectively classify the hematite by conventional beneficiation process. However, the deep reduction-magnetic separation process can be applied to high-phosphorus oolitic hematite iron enrichment. The study found that during the deep reduction process, the phosphate minerals in the ore will be reduced to elemental phosphorus, and a considerable part of the elemental phosphorus enters the metallic iron phase, causing high content of phosphorus in the reduced iron powder [37]. In response to this problem, relevant scholars put forward two solutions: deep reduction of dephosphorization and deep reduction of phosphorus-rich [12]. For the raw ore with phosphorus content less than 0.8%, by adding dephosphorization agent (Na_2CO_3, $Ca(OH)_2$, Na_2SO_4, etc.) the vast majority of phosphorus remains in the slag phase. This way would get the low-phosphorus deep reduced iron powder (phosphorus content ≤ 0.05%) that can be directly used in steel-making [13]. For raw ore containing more than 0.8% phosphorus, by controlling the migration of phosphorus, more than 80% of the phosphorus enters the metallic iron phase. It would get high-phosphorus deep reduced iron powder (phosphorus content ≥ 1.5%), and then use smelting dephosphorization technology to deal with high-phosphorus iron powder, and qualified molten steel at the same time get high-phosphorus steel slag, the high-phosphorus steel slag can be used directly as phosphate fertilizer or acid soil improver. Presently, this technic is not yet widely used because of lacking equipment.

4.5. Others

Other mineral processing and ore metallurgy technology would include the tailings re-separation technology and room temperature collector technology. [12] Due to the low grade of iron ore resources in China, an average of 1 ton of iron concentrates needs to be discharged to 2.5 tons of tailings. With the continuous increase of production capacity of mining enterprises, the discharge of iron tailings has rapidly increased and has become the largest industrial solid waste. Tailings discharge not only occupy a large amount of land, sometimes due to poor management, but also cause tailings dam break, resulting in casualties, environmental pollution, destruction of villages and towns and other serious consequences. The iron tailings usually contain a certain amount of metallic iron with a fine grain size, so the energy consumption of grinding is lower than that of raw ore. Anshan Iron and Steel Mining Company, Qidashan iron plant and Gongchangling beneficiation plant conducted flotation tailings re-separation pilot study. The results show that the pre-enrichment of iron minerals in the tailings can be achieved by the re-separation, grinding-magnetic separation and the iron concentrate with grade greater than 40% can be obtained. And then, via the process of grinding—weak magnetic—strong magnetic—reverse flotation process or 1 rough 1 fine 1 flotation column process sorting, reaching more than 64% of concentrate grade, the recovery rate more than 88% [38–40]. Meishan iron ore processing plant integrated tailings, strong magnetic separation tailings, phosphorus tailings on the basis of a comprehensive analysis of mineralogical characteristics of the re-separation were carried out: iron grade of 18% in the tailings can be concentrated to 56.5%. Experimental studies have shown that the nature of iron tailings in different regions vary greatly, hence iron tailings re-separation process is not the same [13]. Most of the domestic iron ore beneficiation plants use an anionic reverse flotation process to reduce silicon, and the collectors used are fatty acids. Anion reverse flotation process has the advantages of stable production, good indicators, the disadvantage is the collector preparation and the required high flotation temperature (preparation temperature is usually 50–70°C, the slurry temperature is generally 35–40°C). As the result floating pulp slurry needs heating treatment, which increases production costs [41]. Luo et al. [42] developed a new modified fatty acid collector, and flotation tests at 25°C showed that they got grade of 65.79% with 83.01% recovery rate from the Sijiaying iron deposit. This fatty acid collector has good water solubility and collectibility at room temperature [43–46]. Aiming at the flotation of iron ore at room temperature, a series of new efficient collectors with low temperature solubility, strong catching ability and excellent selectivity have been developed in China. The efficient separation of iron ore at room temperature has been achieved for some them. However, at present these new collectors are still in the laboratory research or semi-industrial test stage, and the industrial application process needs to be accelerated.

5. Conclusions

This chapter addresses the topic of iron ore types, structure of import, market analysis, financial aspects, overseas investments, etc. It also covers development of innovative beneficiation processes in China. Probably due to large national land area and multi-period orogeny, from the view of metallogeny, lots of iron deposits developed in China, and the proven total reserves of iron ores are relatively abundant, but mainly low-grade ores. For years, China's iron ore reserves are far from being able to meet the requirement of rapid development of steel industry. China is the world's largest importer of iron ore, which imports accounted for one-third of the world's total in recent decades; however, the buyer has not the final say. The strategic importance of iron ore resources in national economy not only depends on the social value and economic value created by the iron ore exploitation, but also depends on whether the requirements of the steel industry and steel downstream industry, and safety ensuring, economy and sustainability of steel and steel downstream industry. In order to improve the self-sufficiency rate of iron ore and get rid of the shackles of foreign mining giants, a great deal of research work has been carried out by relevant researchers around the efficient utilization of iron ore resources. In the process of fine iron ore beneficiation, ore crushing, roasting-magnetic separation, deep reduction, tailings re-election, low temperature collector research and development has made achievements.

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