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Crucible Smelting in Manchuria

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ABSTRACT On the basis of written accounts of Chinese and European observers, crucible smelting was first practiced in China in Shanxi province as early as the tenth century A.D. These same reports also indicate that the practice spread to other provinces (Shandong and Manchuria) from Shanxi. Because of the language barrier, western scholars do not always find the written records accessible; thus, two papers which originally appeared in the Japanese journal *Tetsu to Hagane* (*Iron and Steel*) and one excerpt from a mining report on Manchuria have been translated into English here.

INTRODUCTION

Crucible smelting of iron ore in Shanxi, China, has been reported by several authors (von Richthofen 1877; Shockley 1904; Read 1912), and, on the basis of their accounts, it seems that the process originated in Shanxi and spread from there to other provinces (Fig. 1). Von Richthofen (1877) examined the numerous temples constructed by the dynasties which were based at Honan-fu (Luoyang) and concluded that the iron industry in southeastern Shanxi flourished more than a thousand years. Another westerner who recorded his observations on the metals industry in China, Shockley (1904), was told by one proprietor of a crucible furnace that his family had been producing iron there since the Tang Dynasty (A.D. 923–926). Thus, the history of crucible smelting in Shanxi appears to have begun at least a millennium ago. While conducting my own research into the origins of crucible smelting in Shanxi (Hara, in preparation), I came across some descriptions of the process in other provinces. One account concerns smelting in Shandong, and the other two are of crucible smelting in Manchuria. From these reports, it seems that the process spread from Shanxi to other provinces in China.

A local gazetteer of Qingzhou,[1] a city in Shandong, is said to contain the first description of crucible smelting in China (Hua 1985). Compiled in the reign of Xianfeng (ca. 1851–1861), it says that in the second year of the reign of Kangxi (1662), Sun-Tingquan[2] invited Shanxi men to begin an iron workshop. Two sorts of iron were mined, the better of which is called Huan-shi [delightful ore] and the other Ying-shi [hard ore]. The iron ore was crushed, mixed with coal, and placed into crucibles which were then set into a rectangular coal fired furnace. If the ore was not reduced to iron in the smelt, the mixture in the crucibles was crushed again, placed in new crucibles, and heated to a higher temperature than was used in the first run. Thus, 2 dou (1 dou = 10.4 l.) of pig iron can be obtained from every shi (1 shi = 103.6 l.) of iron ore. When the iron produced was not of satisfactory quality, it was placed into a wood-fired puddling furnace and heated to very high temperatures. A worker "puddled" the iron using a long iron bar, changing it into wrought iron. In this operation, 20 percent of the iron was lost.

This method of smelting seems to have spread into Manchuria, according to an article in *Tetsu to Hagane* (*Iron and Steel*) in 1917, a then new journal published under the auspices of the Japanese Institute of Iron and Steel) by Ryotaro Shimaoka, the head of a Japanese coal and iron company which became active in Manchuria in the 1910s. His report contained detailed descriptions of the Chinese crucible smelting process and illustrations of the furnaces used for the process, which are especially valuable since earlier reports on crucible smelting lacked measured furnace plans.

[1] Qingzhou in now Yidu, Shandong-sheng.

[2] Sun-Tingquan, born in Yidu, passed the Mandarin Examination in the reign of Chongzhen, Ming, and served Emperor Kangxi, Qing.

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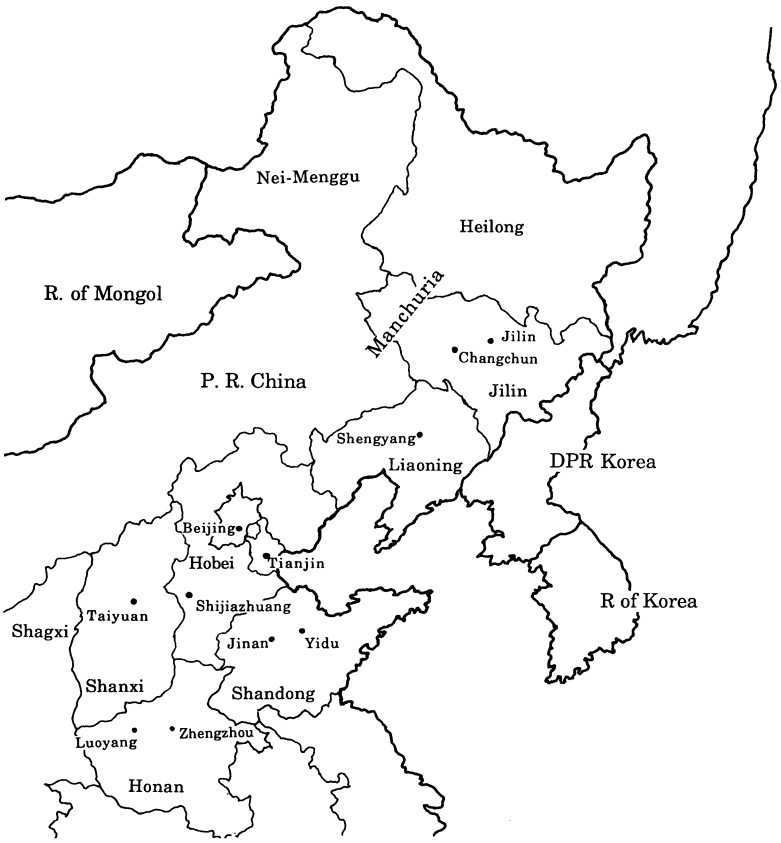

Fig. 1. Map of China showing provinces mentioned

From the figures, the details of crucible furnace construction can be determined—especially the construction of bellows and the melting furnace for casting. It is this report which I have translated into English here, along with another article on traditional ironworking in Manchuria from the same volume of *Tetsu to Hagane,* relating the findings of an investigative team on behalf of the South Manchurian Railway Company.

"Outline of the Old-fashioned Iron Industry in Manchuria,"
by Ryotaro Shimaoka, General Director, Benxihu Coal and Iron Company[3]

[3] This article first appeared in *Tetsu to Hagane* 3.2 (1917): 185–194, and is the result of a survey done by Yoichiro Ishimatu, a member of the Benxihu Coal and Iron Company, in May of 1916.

History

Although it is impossible for us to know the history of the iron industry in Manchuria in detail because of the lack of reliable literature, according to old men's tales and ancient inscriptions it seems to have originated two hundred years ago in the reign of Yongzheng, Qing (1723–1745). As soon as Benxihu became famous for its production of iron ore and coal, a man experienced in iron making came from Shanxi province and set up an iron workshop. Farm implements were produced and sold in Heilongjiang-sheng and Mongolia. Because this man had a monopoly on the profits for several decades, many iron works were set up following his in places around Benxihu such as Saimaji, Sipingjie, and Tiecheng.

Another iron works was built in Dabu at the beginning of the reign of Jiaqing (1796–1819). A man of Shanxi who was based in

Benxihu came to Dabu and set up a small iron works called Fuyuanxing at the southwestern end of Dabu, Quangjiabuzi. Several other iron works were subsequently established. The iron ore for these operations came from local mines such as those in Jiucaiyu, Huapiyu, Shuipojigou, and Luotuobei. These works continued with several periods of ups and downs, until the end of the reign of Daoguang (1823–1851). Reportedly, at that time the social disorder brought about by bandits hurt business, and the iron producers had to stop their operations.

By the beginning of the reign of Xianfeng (1851–1861), social order in Manchuria had gradually recovered, and the Fuyuanxing iron works took the lead in re-opening. At the same time, however, they had to compete with inexpensive, high quality imported pig iron. As a result, most of these iron works as well as other iron operations in Manchuria had to discontinue production.

When the price of iron rose suddenly with the outbreak of World War I, the remaining iron works had the chance to begin production again, so we have the opportunity to know in detail one of the traditional iron-making processes in China.

Outline of a Traditional Chinese Iron Work in Dabu

Location

Dabu is situated in Benxi-xian, Fengtiansheng, in the valley of Tianzifu-gou, a tributary of the Taizi-he River. It lies one hundred km. upstream from Benxihu along the river and sixty-five km. via the land road through Niuxintai and Xiaoshi. Because it is in a valley, the land of Dabu is low and arable and most inhabitants are engaged in agriculture. The leading products are agricultural such as kaoliang, maize, millet, beans, and wines. Other industry includes coal mining and ceramics, so there is also considerable production of coal, wood, and bottles. While Dabu is famous now for its coal resources, it was once a busy iron production center. The climate is "continental," with large differences in temperature between summer and winter. In winter, temperatures fall to minus 30 to 37°C. In summer, it sometimes reaches 30°C. The cold season is from the end of October to the end of March, although there may be several snow falls as late in the year as May. The town has a police post, a primary school, temples, etc. The distances from this town to other towns are as follows: 24.6 km. to Xiaoshi, 14.8 km. to Chengchang, and 11.9 km. to Taizihe.

Material

The main iron ore used is magnetite, while a small quantity of limonite is also mixed and used. The magnetite ore, which is a contact ore, comes from the iron mines of Huapiyu and Shuipojigou [24 km. west, upstream of a tributary of Taizihe, Tanggou] and Luotuobeizi [eight km. south]. Samples of the magnetite ores were analyzed: the ore from Huapigou contained 37.97 percent Fe, 4.31 percent SiO_2, 0.049 percent S, and 0.013 percent P, and the ore from Luotuonbeizi contained 48.01 percent Fe, 13.54 percent SiO_2, 0.029 percent S, and 0.025 percent P. The limonite, a contact ore formed at the interfaces between clayslate and granite, is not so admirable. Half of the magnetite is roasted to hematite and mixed back in with the other half. The entire quantity is then charged. Limonite is not commonly used, although sometimes a small amount of it from a limonite ore bed of Panlajiaozi [4 km. west] is mixed with magnetite for use. The iron content of the resulting ore is higher, but is not recommended for smelting.

The iron work purchases all the ore. The standard price of ore is 4 Xiaoyangying-Yuan per 1000 jin [1 jin = 596.8 g.]. High quality and easily smelted ore costs 8 Qian for 1 jin of ore.

Coal, coke, and firewood are used as fuel. Coal mined from the field at Dabu is of several types, such as Daqinghang, Kabari, Chouzha, and Erjietoujie. It is Erjietoujie coal that is mixed with ore, crushed, and charged into crucibles. Daqinghang and Kabari coals are used for burning in the space between crucibles and heating them. When the Erjietoujie coal burns, it emits white smoke a little, but the Kabari, Chouzha, and Daqinghang coals do not emit smoke and the flame is low like that with coke.

TABLE 1. Analysis of contents of some coals from the Dabu bed

	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Coking property
Daqinghang	0	15.02	77.58	7.40	3.18	good
Erjietoujie	0	14.20	77.90	7.90	0.59	good
Chouzha	0	31.96	60.54	7.50	1.31	good

The chemical contents of some of the coals are shown in Table 1.

Coke is seldom used for smelting ore. Made from coal from the Dabu coalfield, it is chiefly used for melting pig iron when casting. Coke powder is also sometimes added to the charge in crucibles. Firewood is used to ignite coal in the crucible furnace. It is usually well-seasoned, slender branches with a diameter of six to fifteen mm. No flux is used, although a small quantity of flux is added to the clay out of which the crucibles are made.

Construction of the Smelting Furnace, Melting Furnace, Crucibles, and Other Tools

The construction of the smelting furnace (Fig. 2) is not as complex as one would think. At first glance, it is similar to an ore storage bin. The traditional primitive construction may not have changed for several hundred years. It has a rectangular hearth (4.6 m. × 2.8 m.). On one of the short sides, a brick wall (50 cm. thick) separates two blowing fans from the hearth. The wall has two square wind holes (13 cm. × 20 cm.), which lead air from the fans to the wind channels under the hearth. The other short side of the hearth is open. Each long side of the hearth is separated from the outside by a brick wall 50 cm. thick and 1 m. high. The surface of the wall is covered with mud. At the bottom of the hearth, iron plates 12 cm. in width and 50 cm. in length (the same as the width of the hearth) are laid out with 12 cm. gaps between them. They are supported by ceramic pillars 9 cm. high.

Each bellows is set in a wind box, consisting of the front brick wall of the furnace,

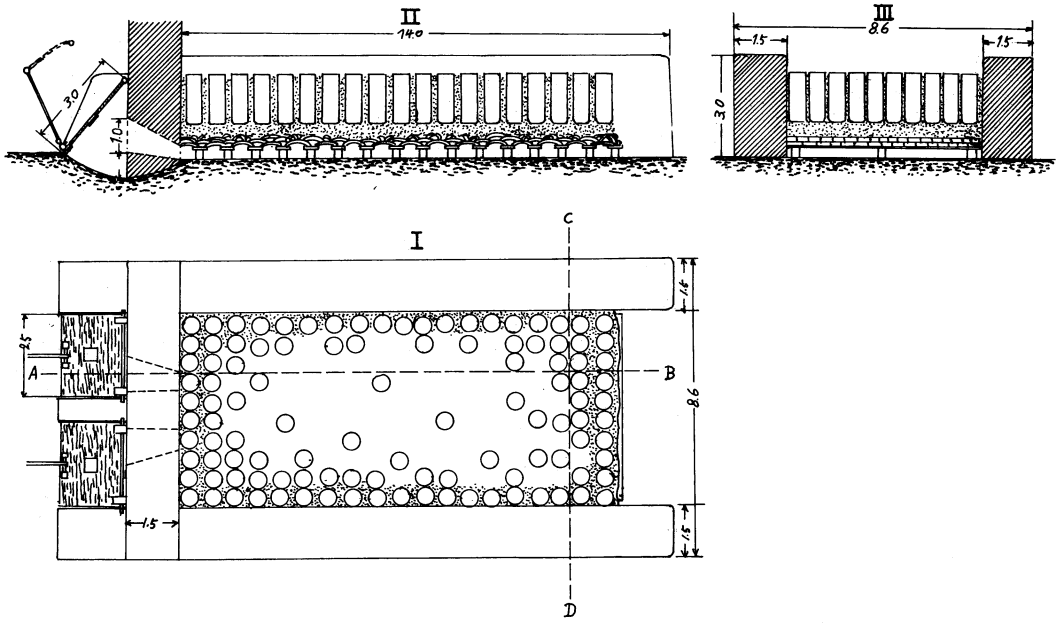

Fig. 2. Construction of a smelting furnace (scale: 1 shaku = 30.3 cm.). I) plan; II) cross section A–B; III) cross section C–D

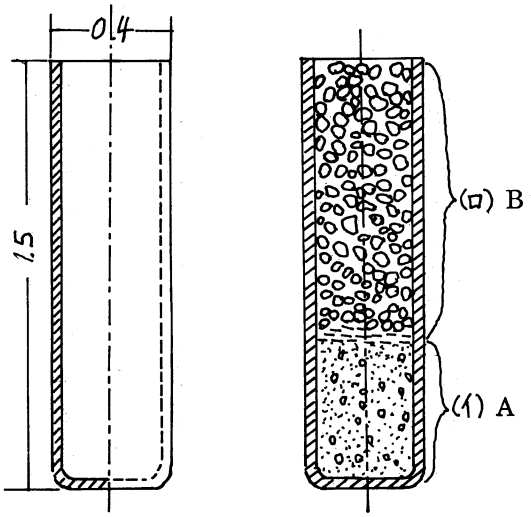

Fig. 3. Cross section of clay crucible

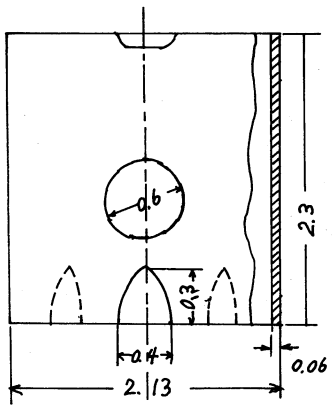

Fig. 5. Cross section of melting cylinder

two side walls, a cylindrical earthen floor, and a fan plate. The fan plate is rectangular (90 cm. × 76 cm.), and it has a square valve window (12 cm. × 12 cm.) and a valve plate at the center. One of the long edges (upper edge) is fitted to the front wall of the furnace with hinges. At the center of the lower edge, a handle-bar is fixed. One end of the handle is connected by a hanging rope to the fan plate, and when the handle is moved forward and backward the fan plate begins a swinging motion.

Crucibles are made from clay. The clay is dried, pulverized, mixed with water, kneaded, and molded into shape (Fig. 3). Before their use, molded crucibles are covered with a thin clay solution and dried in shade.

The melting furnace (Fig. 4) is similar to that of the smelting furnace except that its fan plate is larger (106 cm. × 91 cm), and the handle is operated by two workers. The tuyere made of cast iron is set at the center of the melting cylinder of the furnace. The melting cylinder (Fig. 5) is molded with clay comparable in quality to that of the crucibles but mixed with a small quantity of coke powder. The cylinder has a hole at the center for inserting a tuyere and three places at its lower edge for igniting coke. The furnace's hearth, made from granite, has a

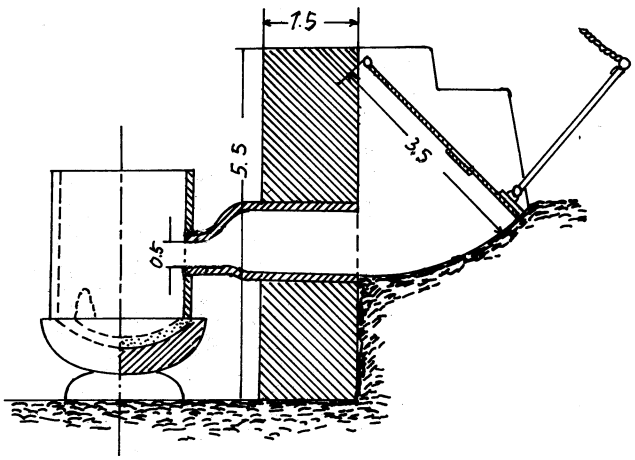

Fig. 4. Cross section of melting furnace

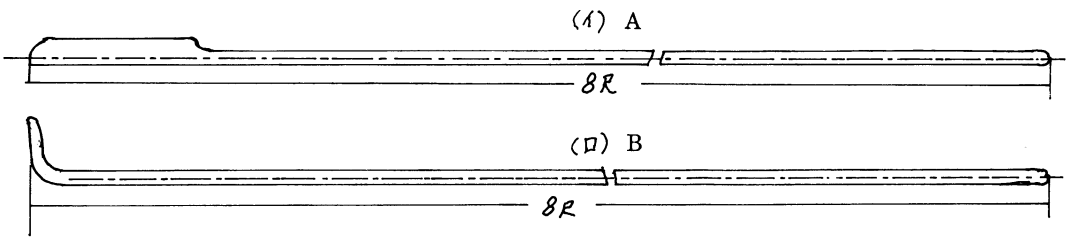

Fig. 6. Drawings of some tools used in iron making: A) scoop with long handle; B) long iron bar

shallow cavity in the center and a tap hole for molten iron. The inside has a clay lining 3 cm. thick.

The other tools used are long iron bars, scoops with long handles (Fig. 6), tongs, iron hammers, casting fittings, and ladles.

Smelting

Iron ore mixed with fuel is charged into thoroughly dried crucibles. The ore is crushed and sieved into small (<15 mm.) and medium-sized particles (15 to 30 mm.). The charge of the crucible consists of ten to eleven parts of ore and three parts of coal. One-third of the total height of the crucible (Fig. 3: A) is charged with small ore and the remaining two-thirds of the inner space of the crucible (Fig. 3: B) is charged with medium-sized ore. Roasted magnetite or limonite is chiefly used for the small ore, but a small quantity of limonite can be used for ores of both sizes.

The charged crucibles are laid out on the hearth. First, iron plates are placed at the bottom of the hearth. Then fragments of used crucibles are heaped on the iron plates to prevent leakage of coke powder. A layer of dried wood branches 6 to 9 cm. thick is then placed on top and 9 to 12 cm. of coal powder are scattered over the branches. The charged crucibles are set in rows on the coal bed. Usually 190 crucibles (ten rows of nineteen each) are put out at one time in a smelting furnace. Coal powder fills the spaces between crucibles.

After the crucibles are laid out, the coal bed is ignited with several bundles of burning firewood thrown into the hearth. The fire burns the layer of branches and the coal bed until gradually flames appear around the crucibles. After several hours of burning, the ash between the crucibles is tamped down with long iron bars, and the coal is again charged using scoops with long handles. When the fire starts to burn again, the crucibles are covered with fragments of used crucible and the open side of the furnace is shut off with a pile of ash and earth. During this operation, two fans are continuously operated. After twenty-four hours of burning, fanning is stopped and the furnace is left to cool down or it is sprayed with water. When the furnace has cooled, the crucibles are taken out. With this step the smelting operation is complete. The crucibles are broken and the iron is extracted.

The product obtained is spongy, raw pig iron containing blow holes and mixed with coke, ash, and slag particles. For every 10 jin of magnetite, 1 jin of limonite, and 3 jin of coal, 5 jin of this spongy pig iron can be made. To figure the total amount of pig produced in each smelting run, one must multiply 5 jin by 190 crucibles, or 950 jin. Chemical analyses of a sample of the pig iron showed it to consist of 1.2 percent C, 1.69 percent Si, 0.20 percent Mn, 0.122 percent P, 0.186 percent S, 93.65 percent Fe, and 2.852 percent dust.

The operation described is possible during every season, but in the hottest season and in the heavy rain it is stopped. The production rate also depends on the need for iron. Usually, the smelting furnace is operated between one hundred and two hundred times in a year.

Casting

The dried melting cylinder is put on the granite hearth. One hundred jin of raw pig iron and one hundred jin of coke are fully

*TABLE 2. Yearly materials use and production output**

	Ore used	Raw pig produced	Castings
1 run	2098 jin [1247 kg.]	950 jin [567 kg.]	500 jin [298 kg.]
1 year	313,500 jin [187 tons]	142,500 jin [85 tons]	7500 jin [44.7 tons]

* 150 runs per year.

TABLE 3. Workers needed for the operation

	Fan	Charge	Furnace	Casting	Odd jobs	Total
Smelting	2	1	2	0	2	7
Casting	4	2	3	1	4	14

mixed and the charge is placed into the cylinder. After charging, the coke is ignited. Once the coke begins to burn, the furnace is sealed and the fan operated. When the iron is melted, the tap hole is opened. The metal which flows out is collected in a ladle and poured into molds. It usually takes four to five hours for melting and pouring.

Plowshares are the main castings produced. Sometimes teapots and pans are also cast, but thin pans can be cast only when the iron is of very high quality. The total weight of the castings is 500 jin per one operation of a smelting furnace. A plowshare usually costs 4 Qian/jin, while a teapot costs 8 Qian/jin. The quantity of raw materials needed and finished product when a smelting furnace is operated 150 times in a year are shown in Table 2. The yield of raw pig iron and castings are: raw pig iron/ore = 45 percent; castings/ore = 27 percent; castings/raw pig iron = 52 percent. Human labor was also necessary to smelt iron (Table 3). Workers are common for the two operations. Wages average 40 Qian.

"Traditional Iron Works in Manchuria, an excerpt from a report of the Mining Department of the South Manchurian Railway Company"[4]

In Manchuria, there has been an iron industry since ancient times. Until pig iron, which was produced in Shanxi and sold at Huolu-tie, was imported into Manchuria, coal and iron ore had been mined locally. Ironwares (farm implements, pots, and pans) were produced by primitive methods in regions such as Benxihu, Saimaji, Tonghua, and Shasonggang. The products were manufactured only to meet immediate demands for small iron goods in Manchuria. Two ironmaking processes were used. One involved the use of crucibles to reduce limonite and hematite to iron with coke powder called *meizi*. The iron was then remelted into pig iron and cast into implements. This was the only Chinese process used in Manchuria, and it is currently in operation at Saimaji. In the other process, which originated in Korea, hematite was roasted and oxidized in a "wall" furnace. The roasted ore was then smelted into iron in an earthen blast furnace. Both processes were primitive and iron making remained a small-scale, family industry.

Benxihu and Saimaji

The iron industry in Benxihu and Saimaji prospered in the middle period of the Qing dynasty, that is, during the reigns of Xianfeng and Tongzhi (1862–1874). The sites where the coal and iron ore were mined and fashioned into iron objects for the whole of Manchuria still exist. However, at the end of the period, the industry experienced a depression because previous overproduction had caused serious depletion of the coal and iron ore resources. In addition, the traditional iron industry had to compete with increased imports of foreign iron.

Most iron works went bankrupt and discontinued their operation. In Benxihu, all the works were closed. In Saimaji, the iron works of Yonglongchang, which produced two hundred tons of iron a year, was the only operation to survive. Plowshares were still the most commonly produced artifacts and ranged in size from 3 to 10 jin [1 jin = 596.9 g.]. The plowshares were sold locally and also shipped from Caohekou-station to Fengtian, Riaoyang, and Andong. The iron ore came from Tixiongshan [50 li southwest of Saimaji, 90 li south of Caohekou; 1 li =

[4] This article first appeared in *Tetsu to Hagane* 3.10 (1917): 1117–1130.

576 m.], and the coal from Pingtingshan. The ore from the Tixiongshan mine was primarily in the form of magnetite which was formed at the boundary between the Cambrian system and the porphyritic rock. This ore is not plentiful and is only of medium quality, but because the deposit is conveniently situated along a transportation route, it has been mined for a long time. The Tixiongshan-Tiekuang-Baosheng Company, Ltd. as well as a few Japanese currently hold the mining rights.

Chengchang

The mountain area around the upstream of Taizihe is rich in iron ore and coal. There were once small iron works everywhere and they were collectively called *Chenchang-Tiechang*. At present, only one iron works has survived, Fuyuanxing, which is located in the small village of Quanjiabuzi between Benxihu and Chenchang, 120 li from Benxihu. This operation yields only fifty-seven tons of pig iron in a year. Iron ore comes from Huapiyu and other mines. For fuel, only Tianshifugou coal is used.

Tiechang

Tiechang is situated about sixteen li east-southeast of Tonghua. There were once iron works in Tiechang because of its proximity to the coal mine. The iron was made from the ores of Qidaogou and other mines. Farm implements, pots, and pans were cast from the iron and sold in the regions of Tonghua and Linjian. At its peak, production reached one hundred tons per year and the site was named Tiechang. At present, however, the works is closed. Previously, iron was also made at other sites in the area, such as Dalizigou and Sandaogou, which were also located near mines.

Shasonggang

Shasonggang is one hundred li west of Hailong, seventy li southeast of Chaoyangzhen. Until recently, in the area surrounding Shasonggang coal mine, Anzihe iron ore was mined and made into iron. At that time, they say that the production was fifty tons per year. The products were once again farm implements which were shipped to Hailong, Chaoyang, Liuhe, Kangping, and Panshi. Sometimes these implements were sold, along with coke produced at Shasonggang to Jiling, however, neither can be found in Jiling any more.

Kuangdongzi Iron Mine

This mine is 230 li south-southwest of Jiling. In 1914, a company called Panshi-Gangxiankuang-Xingya Company, Ltd. was founded and produced 2400 jin of charcoal iron from May to September. But the iron work was not profitable and closed temporarily. The company also mined iron ore from Dazhuquan, located about fifteen li northwest of the Kuangdongzi mine. They had hoped to produce marketable iron from this ore, but, because their method was not good, the work had to be abandoned before actual production began.

Another source which relates something about crucible smelting in Manchuria in the 1920s, the "Report of Fengtian-Benxihu Coal and Iron Company," is also of interest (Department of Agriculture and Commerce 1926).

Benhixu has been a center of iron making in Manchuria since the beginning of the Qing Dynasty. At its peak, the number of family-operated iron smelting furnaces reached about one hundred.

According to a legend handed down by old men of Guajia-zhen, the three iron-making masters Fu-Cifu, Fu-Cichuang, and Wang-Jiande came here in the thirteenth year of the reign of Daoguang (1833). They opened an iron mine, brought iron ore to Benxihu, and sold it. At that time, the price of ore was nineteen diao [1 diao = 100 wen], corresponding to about three Feng-Xiaoyang Yuan per 1000 jin of ore. The operation was eventually suspended because of a lack of funds. In the eleventh year of Xianfeng (1861), the mine was worked again. In the thirteenth year of Dongzhi (1874), Sun and Li also came here and worked. Thus, iron mining by native methods had its peak in the years from Xianfeng to Dongzhi (ca. 1850–1870), when some natives worked in the iron industry during their off season from farming. By the thirtieth year of Gu-

angxu (1887), Russians came and prospected iron ore. With the outbreak of the Russo-Japanese War, their work also stopped.

CONCLUSIONS

As shown above, according to a local gazetteer in Shandong, crucible smelting of iron was transferred from Shanxi to there in 1662. A Japanese engineer, Shimaoka reported at the end of Qing dynasty that the crucible process was introduced in Manchuria by Shangxi men in about 1720s. A Chinese report made at about the same time says that three Shangdong men coming to Benxihu began iron manufacture there in 1833. I believe that all the legends mentioned probably reflect the historical fact that crucible smelting of iron ore spread from Shanxi to Shandong and to Manchuria in the early and middle days of the Qing dynasty.

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