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Cast iron-smelting furnace materials in imperial China: Macro-observation and microscopic study

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A B S T R A C T

Field investigation was carried out to study ancient cast iron smelting furnaces at 15 sites from Imperial China. Petrographic analyses were performed on furnace materials to study the development of metallurgical ceramics used on these furnaces. The results show that furnace materials developed from simple clay material to a composite structure made of stone and clay. During the period from the 4th C. BCE to the 3rd C. CE, rammed clay or stacked clay bricks were used to build the furnaces; from the 7th to the 13th C. CE, furnaces were predominantly made with a durable outer wall constructed from stone, while the refractory material that lined the inner surface of the stone wall was composed of clay, sand and gravel-sized rock fragments. In addition, this paper discusses some aspects of governmental organization, furnace and smelting technology, economics which might influence this development, and examines the relationship between ceramic technology and metallurgy in Imperial China.

1. Introduction

Imperial China[1] developed a technological system of cast iron and steelmaking no later than the 8th C. BCE (Han, 2000). Direct reduction of iron ores to produce liquid iron was accomplished in furnaces that possessed enough height to form both reduction and melting zones, had structural stability, maintained high temperature, and provided silicate material for slag formation throughout the smelting process. It is believed that these cast iron smelting furnaces originated from copper smelting furnaces which, in turn, developed from pottery-making kilns. Because the advanced technology to make pottery and to cast bronze, and to reach and hold high temperatures, had already matured before cast iron appeared, it provided the technological basis to develop cast iron technology (Beijing University of Iron and Steel, 1978; Liu, 1978).

From previous publications, more than 150 ancient cast iron smelting furnace remains were found in 93 sites around China. The earliest one, located in the Jiudian site, Xiping County, Henan Province, is dated back to the late Warring State Period (4th – 3rd C. BCE) (Li, 1990; Henan Provincial Institute of Cultural Relics and Archaeology, 1998). In 117 BCE, Emperor Wu-di of the Han dynasty introduced a state monopoly policy on the iron and salt industries. Due to this policy, many iron workshops were built throughout China, about 49 iron workshops were recorded and nearly 16 of them were located by archaeological study (Li, 1994).

Even though many furnaces were found, the ceramic technology used for cast iron smelting furnaces from Imperial China has never been assessed in detail.

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[1] In this paper, when the term China is used directly, we mean geographic China, when the phase Imperial China is used, we mean historic China. Imperial China is the period from the Qin dynasty to the Qing dynasty (221 BCE – 1911 CE) in general. However, in this paper there are some iron furnaces that were dated a little earlier, to the Warring States period (475 - 221 BCE).

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Metallurgical ceramics, including furnace materials, moulds, crucibles and tuyeres, are all associated with metallurgical processing. Former studies of these associated technologies have focused on resources, performance, and manufacturing technologies of metallurgical ceramics, and then this perspective was used to determine the socio-economic status of a particular site or society (Sahlén, 2013). The overall understanding of ancient refractory materials has been summarized (Freestone and Tite, 1986; Freestone, 1989), and studied in detail in some technological aspects or geological areas (Tylecote, 1982; Tite et al., 1990; Rehren and Kraus, 1999; Rehren, 2003, 2009; Frame, 2004; Martinón-Torres, 2005; Martinón-Torres and Rehren, 2005, 2009 and 2013; Martinón-Torres et al., 2006 and 2008a, b; Bayley and Rehren, 2007; Hein and Kilikoglou, 2007; Hein et al., 2007; Thornton and Rehren, 2009; Meanwell et al., 2013; Sahlén, 2013). In their studies, it is generally believed that local clay was used as the main raw material, but sometimes with quartz, calcite and organic materials added as temper. The studies also showed that ancient materials were not refractory according to modern technological criteria, but that any available clay was used as raw material, and most were good enough for metallurgical purposes (Freestone and Tite, 1986; Bayley and Rehren, 2007).

In summary, the ceramic materials used in conjunction with cast iron smelting furnaces have not been as well studied as pottery, porcelain, moulds, crucibles, and copper furnace refractory lining materials, and the understanding of these ceramic materials is still sketchy. The aim of this research is to understand the developmental history of cast iron furnace materials through both field investigation and scientific research, and to understand the details of the relationship between ceramic and cast iron smelting in Imperical China, as well as from this perspective to examine the social-economic aspects of the Imperial Chinese iron industry.

2. Field survey and macro-observation of furnace materials

Beginning in 2011, the Archaeometallurgy group from USTB, PKU and NUIST investigated some ancient smelting sites. During our investigation, some additional well preserved furnaces and construction materials from 15 sites were measured and observed in detail, in addition to several sites investigated by other institutes, see Fig. 1, Table 1.

2.1. Clay furnaces

From the investigation, it was found that clay was the most common raw material to make furnaces during the late Warring States Period and the Han Dynasty (4th C. BCE – 3rd C. CE). Because the supporting and lining materials of the furnaces were mostly the same, we named these furnaces as simple clay furnace, see Fig. 2. Rammed clay was the main material used during the Warring States Period and the Early Western Han Dynasty, then, clay bricks were commonly used.

These furnaces had a round or oval plan, the height and diameter both appear to grow larger beginning from the Warring States period to the Han dynasty (4th C. BCE – 3rd C. CE); the largest one was found in the Guxing site, Zhengzhou, Henan province. It is believed that many problems were found with the air flow in the round furnaces, and therefore oval shaped furnaces were invented which replaced round furnaces within a short period of time (Liu, 1978).

Because not many iron smelting furnaces of the period from the Wei-Jin period to the Northern and Southern Dynasties (220 AD – 589 AD) were found, detailed information regarding the furnace materials is still lacking during this Period.

Fig. 1. Location of sites which were investigated.

Table 1
Furnace construction material from sites which were investigated.

NO.	Site	Period	Furnace construction material	Reference
1	Jiudian, Xiping, Henan[a]	Late Warring States Period - Han Dynasty (4th C. BCE – 220 CE)	Foundation: rammed clay with charcoal ash and sands Wall: rammed clay blocks	Henan Provincial Institute of Cultural Relics and Archaeology (1998).
2	Kanjiazhai south, Linzi, Shandong[a]	Western Han Dynasty (202 BCE – 9 CE)	Wall: clay bricks	Yang et al., 2013
3	Tieshenggou, Gongyi, Henan[a]	Mid-Western Han Dynasty - Early Eastern Han Dynasty (1st C. BCE – 1st C. CE)	Foundation: rammed clay with sands and coal ash Wall: rammed clay bricks with lining	Zhao et al., 1985.
4	Wangchenggang, Lushan, Henan[a]	Mid-Western Han Dynasty - Early Eastern Han Dynasty (1st C. BCE – 1st C. CE)	Foundation: rarbon→lime→rammed clay→lime→rammed clay with sands and carbon ash Wall: rammed clay with sands, mud and charcial ash	Henan Provincial Institute of Cultural Relics and Archaeology (2002).
5	Guxing, Zhengzhou, Henan[a]	Mid-Western Han Dynasty - Eastern Han Dynasty (1st C. BCE – 220 CE)	Foundation: rammed clay with sands Wall: rammed clay with charcoal ash	Zhengzhou Museum, 1978.
6	Liguoyi, Xuzhou, Jiangsu[a]	Eastern Han Dynasty (25–220 CE)	Foundation: rammed clay Wall: rammed clay with sands, no lining	Nanjing Museum, 1960.
7	Gushishan, Pujiang, Sichuang[a]	Han Dynasty (202 BCE-220 CE)	Wall: Clay bricks	Chengdu Institute of Cultural Relics and Archaeology (2008).
8	Tiechang, Rongxian, Sichuang[b]	Three Kingdoms Period (220–280CE), unclear	Wall: Rammed clay	
9	Linzhou – Anyang – Hebi District, Henan[a]	Han Dynasty (202 BCE – 220 CE) Tang Dynasty – Northern Song Dynasty (618–1127 CE)	Wall: Clay Wall: Stone	Henan Provincial Institute of Cultural Relics and Archaeology (1992).
10	Xiacun, Nanzhao, Henan[a]	Northern Song Dynasty (960–1127 CE)	Wall: Stone	Han and Ko, 2007.
11	Kuangshancun, Wu'an, Hebei[a]	Northern Song Dynasty (960–1127 CE)	Wall: Stone	Han and Ko, 2007.
12	Maijiehe, Jiaozuo, Henan[b]	Northern Song Dynasty (960–1127 CE)	Foundation: built along the cliff Wall: stone	
13	Yanqing, Beijing[b] Shuiquangou Hanjiachuang Sihai	Liao and Jin Periods (916–1234 CE)	Foundation: built along the cliff Wall: outer stone wall with inner lining	Liu et al., 2014; Huang et al., 2015.
14	A'cheng, Heilongjiang[a]	Jin Dynasty (1115–1234 CE)	Foundation: built along the cliff Wall: stone	Heilongjiang Museum, 1965.
15	Zunhua iron factory, Hebei[b]	Ming Dynasty (1368–1644 CE)	Wall: stone	

[a] - Original investigated by other institutes and re-investigated recently.
[b] - Investigated for the first time.

2.2. Stone and clay composite furnaces

There are many furnaces of the Tang dynasty to the Ming dynasty (618 AD – 1644 AD) found and reported in detail in archaeological reports. Most furnaces were built directly along the hillside, in order to obtain a strong outer construction. Most furnaces had a round plan, except some 12th century (the Jin dynaty) furnaces in Heilongjiang and Beijing provinces which were square-shaped. For the furnace materials, stone replaced rammed clay or clay bricks, to be used as the main supporting material. Clay tempered with lots of sands and rock fragments was used as lining materials, which were very different from the simple clay linings in the early times, see Fig. 3.

From the results of investigations, the development route of furnace materials in the perspective of macro-observation is summarized in Fig. 4.

3. Microscopic study

3.1. Materials and method

Materials from three sites were collected for use in the present study, see Table 2, Fig. 5.

The earliest furnace which dated back to the late Warring State Period (4th – 3rd C. BCE) at the Jiudian site, Xiping County, Henan Province (HXJ) was re-investigated and samples taken. The furnace had been excavated in 1987, it was found that the furnace was built along the hillside, and it was made of clay. (Li, 1990; Henan Provincial Institute of Cultural Relics and Archaeology, 1998).

The second site is dated from the 3rd to 1st C. BCE (Kanjiazhai south site at Linzi District, Zibo city, Shandong province), and the third site is dated from the 10th to 13th C. CE (Shuiquangou site, Yanqing county, Beijing). The Kanjiazhai south site (SLK) is a part of the capital site of the Qi state which was a political, economic, cultural and military center in the Shandong peninsula during the Warring States period and the Han dynasty (476 BCE –220 CE). Many of the pits in this site still contained numerous iron smelting remains including furnace materials, slag and iron artifacts which dated back to the Western Han dynasty (3rd - 1st C.BCE).

The Shuiquangou site (BYS) is located in the mountain area northwest of Beijing. Many other smelting sites and iron deposits were found nearby, which may illustrate that this area was an iron industry center during the Liao and Jin period (916–1234 C. CE). Two furnaces of the Liao dynasty and two other furnaces of the Jin dynasty were discovered and unearthed in a small region within this site. Furnace materials from this site were processed and published in a preliminary study (Liu et al., 2014), but some of the results in this former publication were checked and re-examined here. For all studies, samples of rammed clay, clay bricks, stone and furnace linings were examined.

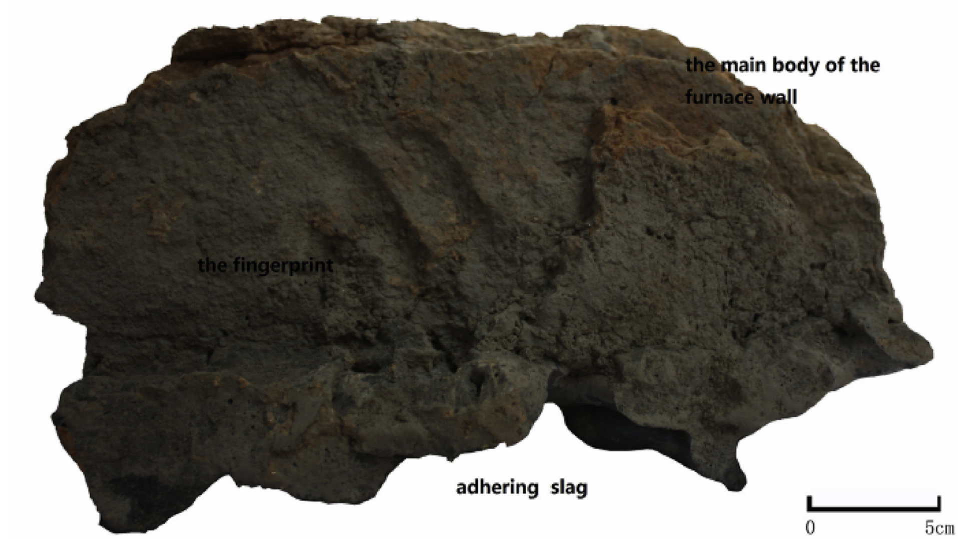
Fig. 5 shows that the furnace materials from the SLK and BYS sites were found to be very different and represent the major features of furnace materials in their respective types.

Thin sections of these materials were made and used to observe their petrographic microstructures. Samples about 5 cm were taken to make radial sections from the inner surface to the outer surface. Sections having a thickness of 30 μm were made in the Laboratory of Orogenic Belts and Crustal Evolution of Peking University. These sections were then studied both in plane polarised (ppl) and cross polarised light (xpl) at the Archaeometallurgy Laboratory of PKU, the Department of Material Science and Engineering of Lehigh University and the Center of Materials Research

Furnace at Jiudian site, Xiping, Henan

Furnace foundation at Guxing site, Zhengzhou, Henan

Furnace at Gushishan site, Pujiang, Sichuang



Furnace materials excavated from Kanjiazhai south site, Linzi, Shandong

Fig. 2. Simple clay furnace during the Warring States Period and the Han dynasty.

for Archaeology and Ethology of MIT, using petrographic techniques promoted by Stoltman (1989, 2001). A quantitative assessment of the materials was made by performing point-count analysis, each sections were directly point counted under the microscopic vision (25×) by using Swift Model F point counting instrument at MIT, and then quantifying the proportion of matrix, pores, and three classes of grain sizes: silt (<67 μm), sand (67–1000 μm) and gravel (>1000 μm).

3.2. Results and analysis

The petrographic analysis illustrated a clear difference between the furnace materials (both supporting and lining material) from the HXJ, SLK site and the linings from the BYS site. Petrographic sections of samples from the HXJ and SLK site show them to consist of approximately 60–70% clay matrix with the balance being silt, see Figs. 6 and 7, Table 3. However, linings from the BYS site have

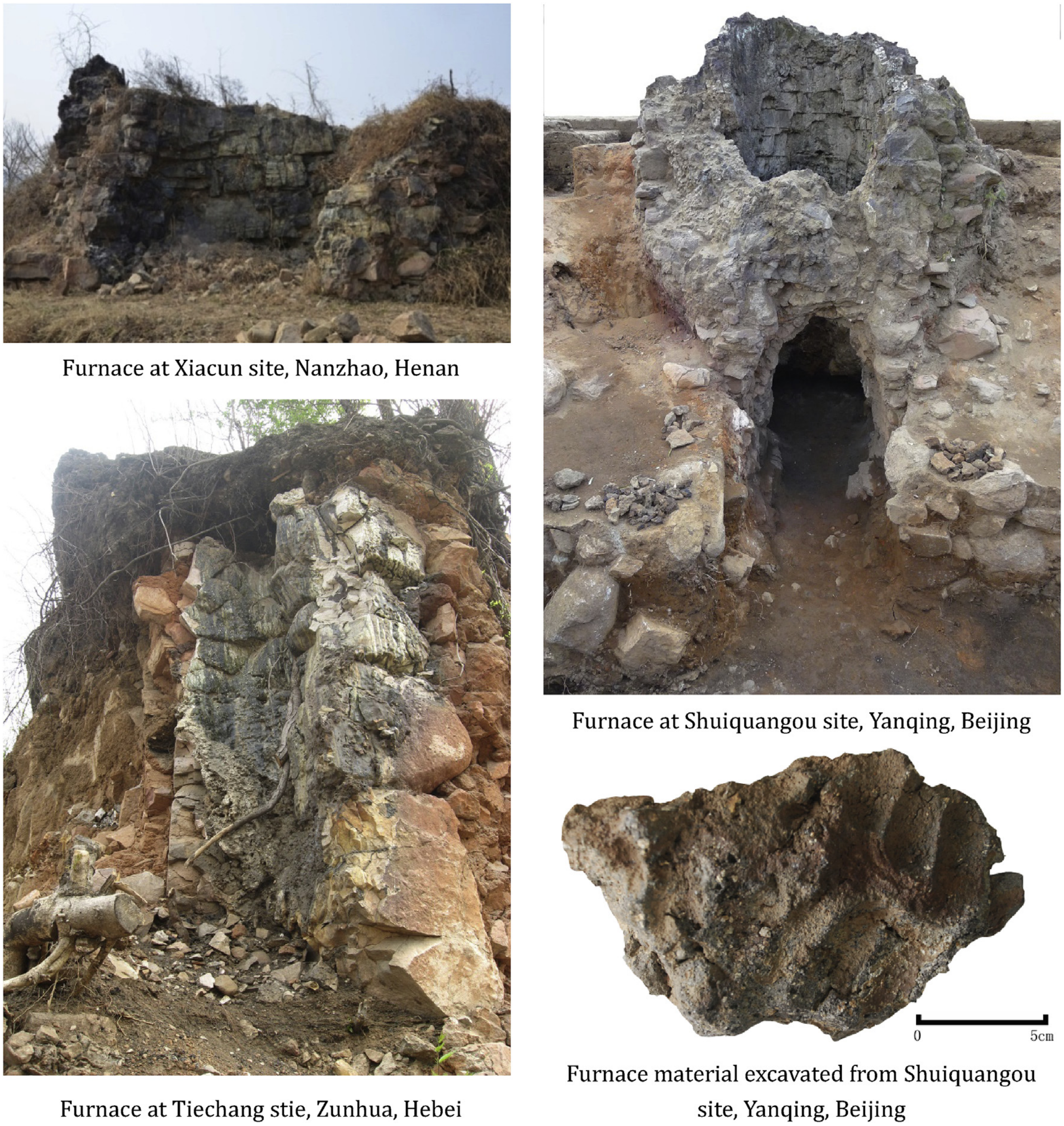


Fig. 3. Stone and clay composed furnaces from the Tang dynasty to the Ming dynasty.

Furnace Materials	Warring States Period	Western Han Dynasty	Eastern Han Dynasty	The Period of Three Kingdoms, Wei, Jin, Northern and Southern Dynasties	The Period of Tang, Song, Liao, Jin and Yuan Dynasties	Ming Dynasty
Supporting Material	Clay (Rammed Clay or Clay bricks)			Uncertain	Stone	
Lining Material	Mostly clay			Uncertain	Sand and rock fragments tempered material	

Fig. 4. The development route of the cast iron smelting furnace materials from the perspective of macro-observation.

Table 2
The location, types and number of furnace material samples.

Site	Supporting material	Lining material
Jiudian, Xiping, Henan (HXJ)	Rammed clay (8)	
Kanjiazhai south, Linzi, Shandong (SLK)	Clay bricks (8)	
Sahuiquangou, Yanqing, Beijing (BYS)	Stone	Sand and rock fragments tempered material (21)

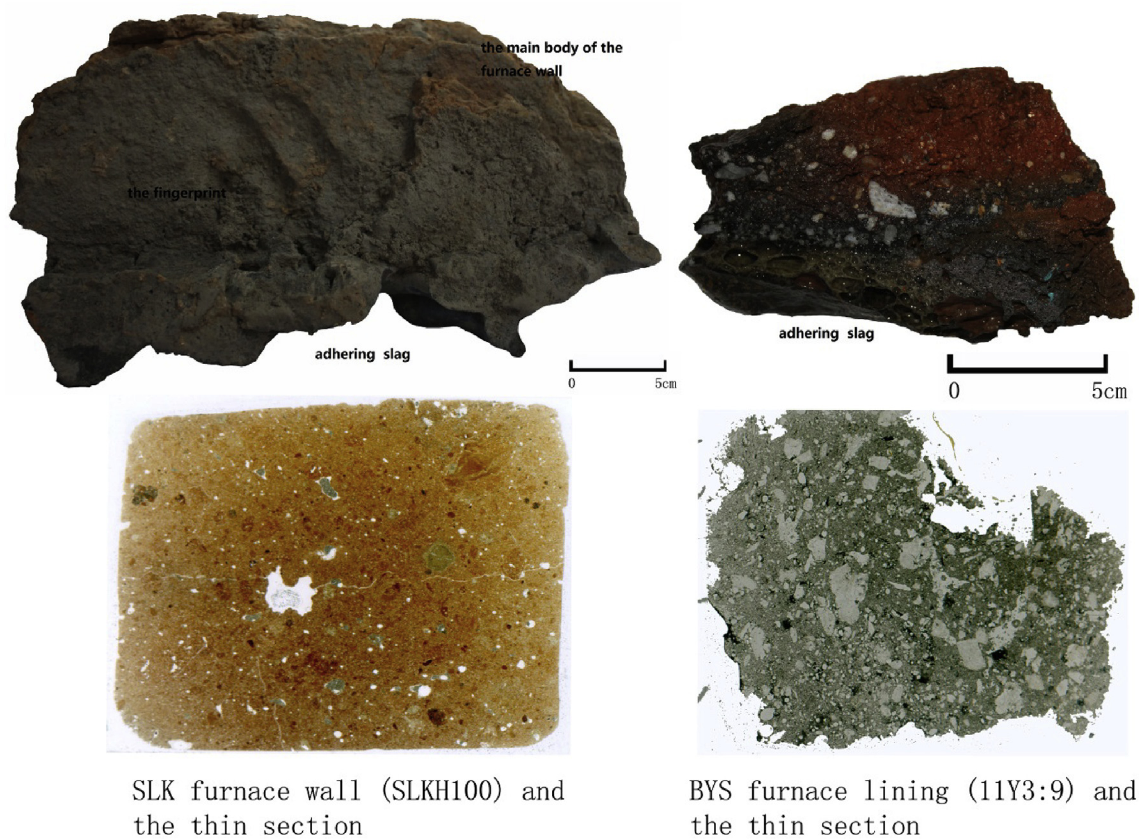


Fig. 5. Furnace materials from the SLK site (left) and the BYS site, showing different macrostructures representative of their respective furnace material.

only a small proportion of clay matrix and indicate the addition of sand and gravel sized rock fragments, see Fig. 8, Table 4.

Fig. 9 is a ternary plot comparing the fractional amount of matrix, inclusions and porosity for SLK and BYS materials. It can be seen that not only the fractional amounts of clay matrix, inclusions and pores hugely different (Fig. 10), but also the size of inclusions and pores in the two materials are very different.

From the petrographic results to follow, it can be shown that the original source of raw materials and the manufacturing technology of the SLK materials can be inferred. According to previous research on clay brick (Yang et al., 2014), pottery kiln wall and bronze casting mould materials (Freestone, 1989; Liu et al., 2013), loess in Northern China has been used for a long time. In this present research, it is believed that the SLK materials come from local earth, which is similar to loess. It appears that organic materials were not added as temper in this site. The clay was then rammed or shaped into

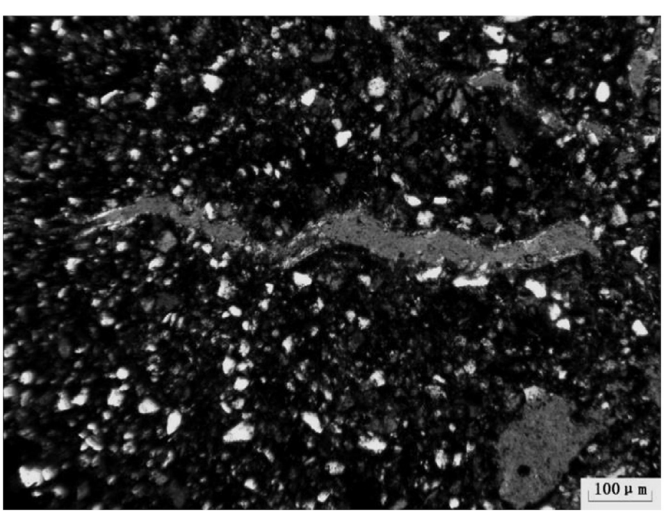


Fig. 6. HXJFM5, 10X, XPL, furnace wall, rammed clay, clay matrix is nearly 70% with silt balance, a pore in a long-formed shape.

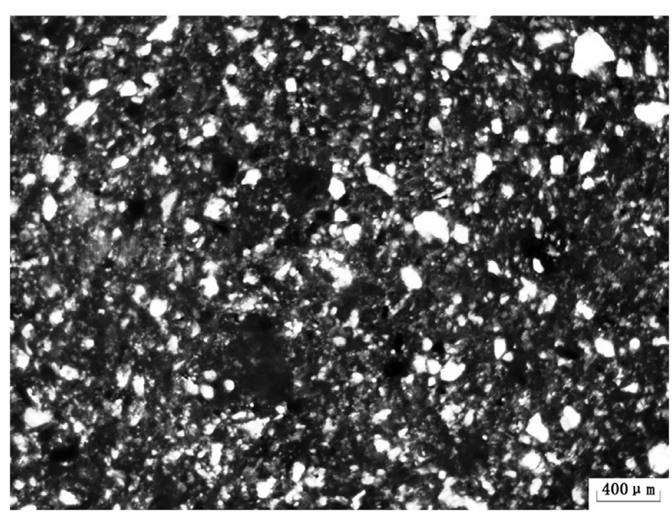


Fig. 7. SLKH100, 25X, XPL, furnace wall, clay bricks, clay matrix is nearly 70% with silt balance.

Table 3
Point counting results of HXJ and SLK furnace materials (V%).

Sample type	Sample No.	Matrix	Silt	Pores	Others
Rammed clay	HXJFM1	62.3	21.7	12.7	3.3
	HXJFM2	60.7	21.7	17.0	0.7
	HXJFM3	60.3	20.3	18.7	0.7
	HXJFM4	70.0	19.0	9.3	1.7
	HXJFM5	60.0	20.7	16.7	2.7
	HXJFM6	58.7	20.0	21.0	0.3
	HXJFM7	57.3	16.7	17.7	8.3
	HXJFM8	66.7	23.0	9.3	1.0
Clay bricks	SLQFM1	74.3	17.7	4.0	4.0
	SLQFM2	66.7	21.0	7.0	5.3
	SLQFM3	52.0	32.7	11.0	4.3
	SLQFM4	63.5	21.2	9.5	5.8
	SLQFM5	62.4	23.3	6.3	8.0
	SLQFM6	61.0	24.2	9.6	5.2
	SLQFM7	73.4	18.8	4.8	3.0
	SLQFM8	59.4	16.4	15.2	9.0

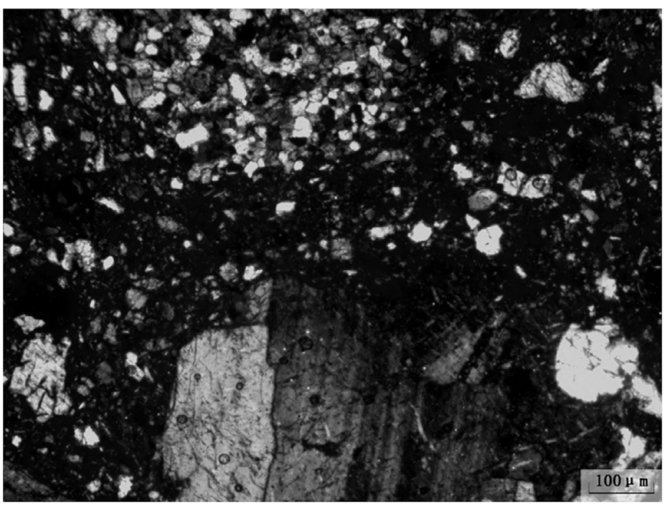


Fig. 8. BYS11Y3:9, 10X, XPL, furnace lining, with very small proportion of clay matrix, indicating the addition of sand, and showing gravel sized rock fragments.

square bricks by mixing with water, and then fired. At the SLK site, it is believed that the clay used for joining was tempered with organic materials (such as rice or wheat stalks). Each surface of the bricks was coated with clay, then the bricks were piled up and shaped into a circular furnace wall.

There were two main types of raw materials used in the BYS furnaces: stone and local earth. Stones at the BYS site are mostly quartzite and granite, which could be locally collected. The stones were broken into two sizes: a large size (30–50 cm) and a medium size (30 cm). They would then have been piled up into two circles: an outer large sized stone wall and inner medium sized stone wall. After the stone wall was built, sand and gravel sized rock fragments were added as temper to local earth (which might not have been carefully selected and screened), mixed with water, and then pasted or brushed on the inner surface of the medium sized stone wall as furnace linings. This type of material was also used as joining material, and shaped into square bricks as tapping channel lining, as well as used to make side-opening material with slag material used as temper.

4. Discussion

From the field investigation, it was found that there was a major change of furnace construction materials in different time periods. During the 4th C. BCE and 3rd C. CE, the materials were simple clay, and these early furnaces were made from rammed clay or from stacked clay bricks. However, after the 7th C. CE, furnaces were mostly made with a durable outer wall constructed with stones, and the interior lined with a replaceable clay refractory material. It seems that the furnace construction materials developed from simple clay material to stone and clay in a composite structure, see Table 5.

Table 4
Point counting results of BYS linings (V%).

Sample No.	Matrix	Silt	Sand	Rock fragments	Proes
11Y1:6	23.5	5.4	16.0	37.8	17.3
11Y1:8-1	50.6	9.4	20.5	6.7	12.8
11Y1:8-2	27.0	7.0	21.6	28.3	16.0
11Y1:8-3	24.0	5.0	13.5	39.2	18.3
11Y1:10	22.4	5.1	16.1	35.2	21.2
12Y1:1	28.8	6.9	19.7	15.4	29.2
12Y1:3	49.4	9.1	18.3	7.8	15.4
12Y1:4	39.6	7.5	18.1	17.2	17.6
12Y1:5	52.0	8.9	17.8	8.0	13.3
11Y3:3	18.0	6.5	14.5	50.2	10.8
11Y3:8	27.7	7.0	17.7	35.4	12.2
11Y3:9-1	34.7	7.3	17.5	25.0	15.4
11Y3:9-2	31.8	6.4	17.0	29.1	15.7
11Y3:9-3	34.2	8.2	16.8	22.9	17.9
11Y3:10	24.2	5.6	14.9	24.9	30.4
11Y3:12	29.1	4.5	9.4	37.6	19.4
11Y3:14-1	30.0	7.6	19.0	21.3	22.0
11Y3:14-2	28.3	8.4	20.3	23.0	20.0
11Y3:15	32.6	7.8	21.4	27.6	10.6
11Y3:16	32.4	7.7	17.4	27.4	15.1
12Y3:7	34.1	6.1	14.2	29.6	16.0
12Y3:8	29.2	8.1	21.5	28.6	12.6
12Y3:9	29.5	5.3	15.2	35.3	14.7
11Y4:5	25.2	4.4	20.2	34.2	16.0
11Y4:13	22.4	5.2	20.2	30.1	22.1
11Y4:15-1	29.2	5.6	16.1	24.2	25.0
11Y4:15-2	26.7	3.9	14.3	32.0	23.1
Average	31.0	6.6	17.4	27.2	17.8

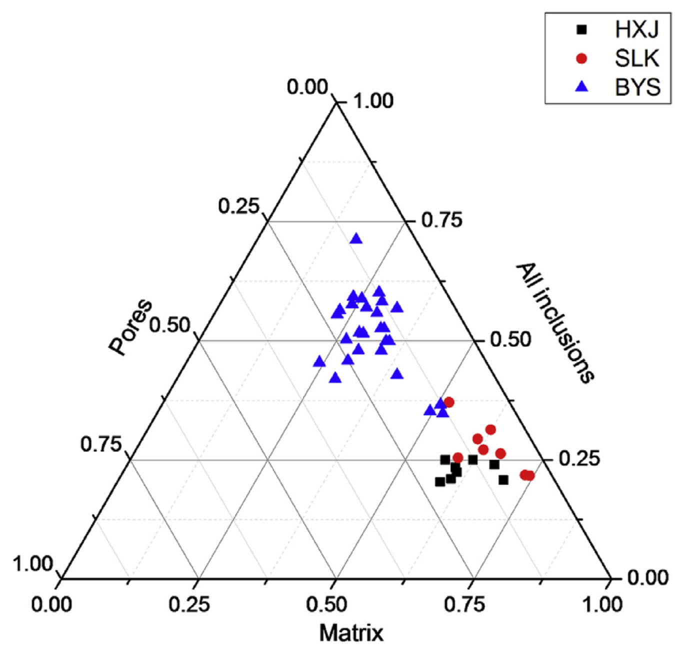


Fig. 9. Ternary diagram showing point counting results of HXJ, SLK walls and BYS linings.

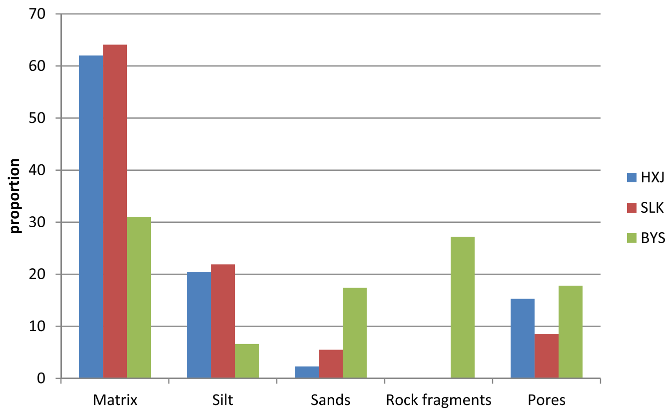


Fig. 10. Comparison of petrographic microstructures from HXJ, SLK materials and BYS linings.

The differences between early furnace materials and later ones were also shown in the microstructure. There are significant amounts of sand and gravel sized rock fragments present in the late materials, and the size of these inclusions are not as uniform as those in the early materials which only have silt sized pure quartz particles. It thus appears that the materials changed during these time periods. In the early period, clay materials were always used, but later, due to the large amounts of sand and rock fragments, clay makes up a much smaller proportion in the refractory materials.

From this major change many questions arose, such as: What are the different technological features? And, did this change influence the smelting technology? Most importantly, why did this change occur?

For the technological features, it is believed that the later materials allow for a much more advanced cast iron smelting technology. Special compositions are required which allow densification without excess slumping in order to achieve hardness and impermeability of the macro and micro structures. Sand and gravel sized rock fragments in a mixture of a fine particle matrix provide for an overall self-correcting composition; as the temperature and firing time increase, more liquid forms, but more sand and rock fragments dissolve, which then increases the proportion of silicate liquid. This type of more advanced material, which has refractory grains dispersed in a viscous silicate liquid containing an extensive network of fine crystallites stiffens the liquid and prevent excessive slumping (Vandiver and Kingery and Vandiver, 1986: 251). Also, the later materials have a higher porosity, which allows generated gases to easily escape through the pores; and, voids and particles are able to stop the expansion of cracks and prevent the failure of whole structures (Kilikoglou et al., 1998; Tite et al., 2001).

Meanwhile, the use-life of the later furnace might be longer. The wall of large piled stones made the furnace structure much more stable, and the inner lining was really sacrificial material, which means it was not only easily made, but also easily repaired after a cycle of metallurgical operation. In contrast, the rammed clay wall would easily melt and cause problems on keeping the structure stability; and if the inner clay wall was seriously vitrified, the whole furnace would be abandoned. As a result, it can be suggested that the later furnaces which used sacrificial material may have had a longer use life than the early furnaces, see Table 6.

Moreover, thick rammed clay walls would take a long time to dry sufficiently for the furnace to be used. Stone walls with a thin clay lining could be usable much sooner, which made the later furnace more efficient in operation.

It is well known that China developed an advanced ceramic technology before metalworking was invented. The earliest pottery in China appeared nearly 20,000 years ago (Wu et al., 2012). This ceramic technology provided the basic capability for making, shaping and replication of refractory materials, as well as drying and firing technology which then led to an understanding of metallurgical smelting and processing (first copper smelting, bronze casting, and then cast iron smelting). From this current research, we can observe the development of the ceramic refractory technology as it evolved in different periods. In the early period, many ceramic operations were involved, such as ramming of clay or making of clay bricks, which included careful screening, shaping, drying and heating. However, in later times, clay was only used on linings which were truly sacrificial materials, shaping, drying and heating were not carefully processed, this progress involved much less effort in ceramic work than in the early period.

Also, the organization of the working group might be changed. During the early period, the government maintained more or less nominal control of iron production. This was formalized in 117 BCE. In the late period, more family or small groups organized business in a given place by themselves under the permission of the government appeared (Liu, 1975) became more popular. Also, in the late period, the furnaces were located mostly in mountain regions nearby iron deposits, but isolated from other technological industries. However, due to the availability of sources and/or the size of bodies of labor, this organization changed, and the methods of making furnace materials changed as a consequence.

As a result, furnace materials in the late period were much easier to fabricate, refractory brick work was not required, and

Table 5
Comparations of different furnaces.

Items	Early (4th C. BCE – 3rd C. CE)	Late (7th C. CE – 13th C. CE)
Location	Urban workshop areas, shared with other crafts (also some sites nearby iron deposits)	Isolated, nearby iron deposits
Construction	Rammed clay OR clay bricks	Stone outer wall with replaceable clay lining
Materials	Mostly clay with silt sized quartz particles	Supporting material: Local stone; Lining material: Smaller proportion of clay with sand/gravel sized rock fragments
Use-life	Shorter	Long

Table 6
Comparation of furnaces' use life from archaeological evidence.

Furnace	Period	Size of burned soil	Furnace repair and re-use situation
Wangchenggang, Lushan, Henan (Henan Provincial Institute of Cultural Relics and Archaeology, 2002.)	1st-3rd C. CE	<1.5 m	Re-built on the foundation once
Shuiquangou, Yanqing, Beijing	10th-13th C. CE	2-3 m	Replaced lining for every use, thickened walls three times

could be used for a long time. These factors might also have caused reduction of input labor and resources, these improving the economics of operation.

Our ongoing research will continue to investigate more additional sites and samples, and to compare them with local resources, pottery and porcelain, as well as to compare them with different metallurgical ceramic materials, in order to gain a deeper understanding of ancient refractory technology in China.

5. Conclusions

This paper represents the first detailed study of cast iron smelting furnaces in China that combines field investigation with petrographic study.

It appears that the ceramic materials found in archaeometallurgical sites were specifically made in order to provide technological assistance for metallurgical processing. In China, hundreds of large cast iron smelting furnaces were found from different periods and regions, this research aimed to investigate most of these. We obtained detailed scientific information about furnace construction, and surveyed the historic development of Chinese cast iron smelting refractory materials, and have gained a better understanding of the Imperial Chinese iron industry from this perspective.

This study shows that furnace materials developed from simple clay material to a stone and clay composite structure. Rammed clay or stacked clay bricks were used during the 4th C. BCE and 3rd C. CE, while, from the 7th to 13th C. CE, refractory materials of clay with sands and gravel sized rock fragments were used to line the inner surface of the stone wall.

The technological change was not only related to different resources or manufacturing technologies, but also because of different styles of governmental organization. This concept allowed us to see the changing relationship between the development of ceramics and metallurgy in ancient China, and their parallel path of change. Based on historical records, it appears that the organization of the working group for cast iron production changed from state-control to a small organization during the broad history of Imperial China. Furnaces used during the late period show many technological improvements such as the use of a replaceable sacrificial clay refractory lining, which made the furnace easy to repair and which might have produced a longer use life. All in all, easier methods of furnace fabrication, smaller organization, better refractory quality and lower cost material might all have contributed for this development to have happened.

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