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

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ABSTRACT

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.

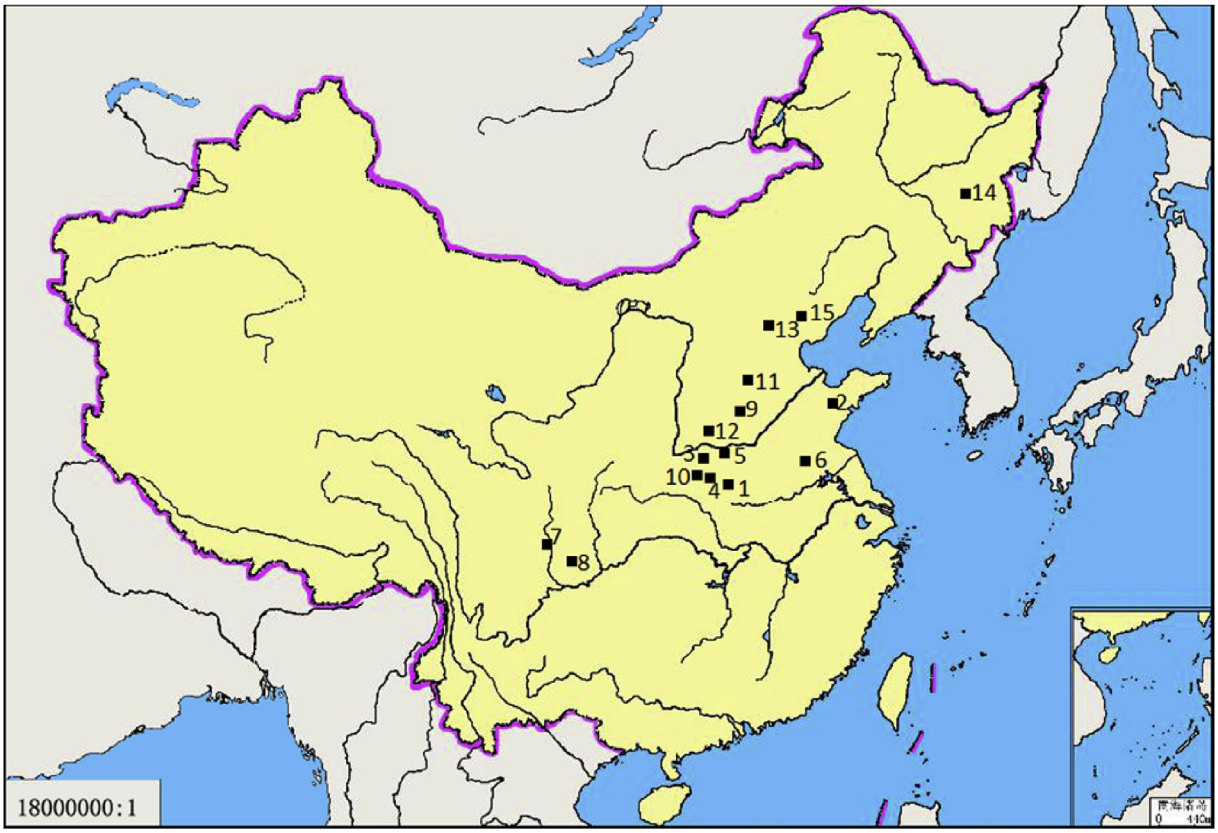

Fig. 1. Location of sites which were investigated.