Journal of Archaeological Science 43 (2014) 278–288

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Not so efficient, but still distilled: the technology of Qing Dynasty zinc production at Dafengmen, Chongqing, southwest China

Wenli Zhou [a,*], Marcos Martinón-Torres [b], Jianli Chen [c], Yanxiang Li [d,**]

[a] Institute for the History of Natural Sciences, Chinese Academy of Sciences, Beijing 100190, China
[b] UCL Institute of Archaeology, 31-34 Gordon Square, London WC1H 0PY, UK
[c] School of Archaeology and Museology, Peking University, Beijing 100871, China
[d] Institute of Historical Metallurgy and Materials, University of Science and Technology Beijing, Beijing 100083, China

ARTICLE INFO

Article history:
Received 30 May 2013
Received in revised form
6 January 2014
Accepted 6 January 2014

Keywords:
Zinc distillation
Retort
Crucible smelting
Workshop location
Efficiency

ABSTRACT

The technology of zinc distillation at three large-scale production sites in Chongqing, southwest China, dated to the Ming Dynasty (AD 1368–1644), has recently been reconstructed from the analysis of production remains (Zhou et al. 2012). This paper presents the study by OM and SEM-EDS of zinc production remains from the later site of Dafengmen, in the same region, dated to the Qing Dynasty (AD 1644–1912). The main aims are to add to our characterisation of the Chinese technological tradition of zinc distillation, and to use a comparative approach to explore adaptations to different geological and sociopolitical contexts. The results reveal that at Dafengmen zinc-makers employed a broadly similar technology to those at the Ming sites, based on distillation by ascending in ceramic retorts, but they used lower grade oxidic zinc ores, a lower proportion of reducing agents, and elongated retorts of inferior performance, leading to greater losses of zinc. This is in spite of Dafengmen's ideal location near the necessary raw materials. The reasons for the lower technical efficiency at the later site are explained in terms of different social, political and economic constraints.

1. Introduction

Zinc made a relatively late appearance in the metallurgical history of China. As a volatile metal, its production required sophisticated distillation installations. The production of this metal played a special role in both the technological and economic history of Ming and Qing China: as a key constituent of the copper alloy brass, zinc was employed for coinage (Zhou, 2004; Wang et al. 2005) and also exported via long-distance maritime trade (Bonnin, 1924; de Ruette, 1995; Souza, 1991; Craddock and Hook, 1997).

Our understanding of Chinese zinc distillation technology has traditionally been limited by a lack of studies of production remains. The discovery of nearly 20 zinc smelting sites dated to the Ming Dynasty (AD 1368–1644) along the Yangtze River in Fengdu, Chongqing, southwest China since 2002 has allowed the first high-resolution, contextualised technological reconstruction of zinc distillation (Fig. 1). Zinc production remains from three of these sites, Miaobeihou, Puzihe and Muxiexi, have been analysed and the technology employed has been reconstructed in great detail. The analytical results revealed the use of large-scale installations for zinc distillation with retorts made of jar-shaped pots, condensers, pockets and lids, all well designed with formal and material properties that optimised performance during zinc distillation by ascending. The retorts were charged with iron-rich oxidic zinc ores, coal and charcoal; a high temperature of around 1200 °C and highly reducing atmosphere were achieved to reduce the zinc ores; the zinc vapour formed within the pots was cooled and collected in the condensers. The mass production of zinc in Fengdu was probably set up to supply government mints (Liu et al., 2007; Zhou et al., 2012; Zhou, 2012).

A search was made for the possible ore sources which supplied these zinc smelting sites in Fengdu. The nearest lead-zinc deposits, at Laochangping in Shizhu (Fig. 1), about 50 km southeast of the Fengdu sites, were investigated during several field trips from 2004 to 2010. These exploratory surveys revealed large amounts of tap slag from lead/silver or copper smelting (Xie and Rehren, 2009) as well as old zinc mine workings in the Laochangping region. The minerals found inside Yushi Cave, one of the largest old zinc mines,

* Corresponding author.
** Corresponding author.
E-mail addresses: zhouwenli@ihns.ac.cn (W. Zhou), m.martinon-torres@ucl.ac.uk (M. Martinón-Torres), jianli_chen@pku.edu.cn (J. Chen), liyanxiang@metall.ustb.edu.cn (Y. Li).

0305-4403/$ – see front matter
http://dx.doi.org/10.1016/j.jas.2014.01.009

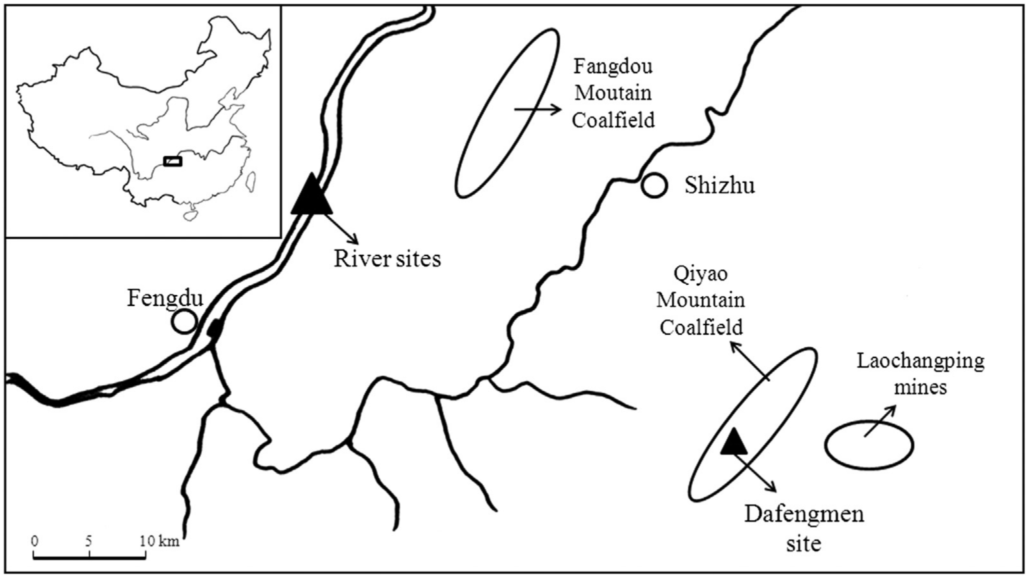

Fig. 1. Map showing the locations of the Ming production sites in Fengdu ('River sites'), Dafengmen site in Shizhu, the Laochangping mines, and the Fangdou and Qiyao Mountain Coalfields.

were mainly iron-rich zinc carbonates, similar to those excavated at Miaobeihou, one of the Fengdu sites (Zhou et al., 2012), indicating that the Fengdu sites could have used zinc ores from this region. Four zinc smelting sites were also found a few kilometres west of the Laochangping mines. Several rectangular furnace foundations were found and some were excavated. One of these zinc smelting sites, Dafengmen (Fig. 1), was investigated in August 2010, and various types of production remains were collected and analysed to reconstruct the technology employed. With dates indicating a production peak during the Qing Dynasty (AD 1644–1912), and a location broadly in the same region but with significantly different topography and resource environment, the site offered an excellent comparison with the earlier Ming sites, characterised previously.

This paper presents the analytical study of the Dafengmen remains as the basis for a technological reconstruction and a comparison with the Ming technology. Factors considered include retort design, raw material selection and processing, performance and efficiency, and environmental and sociopolitical constraints. It is shown that, in spite of a seemingly ideal location in close proximity to the zinc ores, fuel and refractory clay needed for the industry, the Qing zinc production technology appears technically less efficient. These differences are explained in terms of different sociopolitical constraints.

2. Site description

Dafengmen is about 7–8 km west of the Laochangping region, situated in a long narrow valley between mountains. Dafengmen literally means 'large wind gate', and it is thus named because it is very windy. Abundant retorts fragments and slag were scattered all over the valley area. Trees and plants are rarely visible in this area, probably because of the severe pollution caused by the metallurgical debris. The size of the site has been estimated by a modern mining and smelting company who planned to re-process these smelting remains to extract zinc for the production of zinc oxide. They estimated that the Dafengmen site is around 2 km in length, 250 m in width; the heaps of retorts and slag are 1.5–3 m thick, weighing approximately 250,000 tonnes.[1]

[1] Online source: http://wenku.baidu.com/view/cef1ff3f5727a5e9856a61bb.html.

Radiocarbon dating of charcoal samples from the site indicates that the production mainly dates to the Qing Dynasty (AD 1644–1912) (Table 1). There is also literary evidence from *Local Gazetteer of Shizhu* saying that mass production of zinc began from 1770 and continued until the 1840s in the Laochangping region (RGALHS, 2009). One charcoal sample (BA07558) was dated to the Song Dynasty (AD 960–1279), but it is highly unlikely that this date corresponds with the zinc smelting activity, since it would predate any evidence of zinc production in China by several centuries; perhaps the charcoal was made from an old tree or simply derived from earlier activities in the area.

3. Methods

The methods and instrumentation employed are exactly the same as for the previous study of Ming remains (Zhou et al., 2012), and they are repeated here for convenience. Different parts of retorts and slag from Dafengmen were selected for analysis. Several samples were chosen from each category of material in order to assess their internal variability. Samples were named with three capital letters followed by a number. The first two letters SD refer to the Dafengmen site, while the third letter B or T denotes bottom or top parts of retorts respectively. The samples were mounted in epoxy resin and polished to 1 μm for optical microscopy (OM) and scanning electron microscopy-energy dispersive spectrometry (SEM-EDS) examinations.

The OM used was a Leica DM LM. Microphotographs were taken in plane polarised reflected light (PPL) and cross polarised reflected light (XPL).

The SEM used was a Philips XL30 environmental SEM with an Oxford Instruments spectrometer package. The polished blocks were carbon coated. They were observed in secondary electron (SE) and backscattered electron (BSE) modes, and analysed using the EDS system. The acceleration voltage applied to all analyses was 20 kV, the working distance 10 mm, the spot size 5.0–5.6, the beam current adjusted to a deadtime of 35–40% and the livetime 50 s. Given the heterogeneous nature of most of the samples studied, the bulk compositions of the samples were obtained by averaging five measurements of large areas of ∼2 by ∼2.5 mm. It is accepted that analysing such large areas of heterogeneous and often porous materials may compromise accuracy, but this was still deemed the