Texts and Technologies in Chinese Silver Metallurgy, Twelfth to Nineteenth Centuries

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Abstract: The silver metallurgy of late imperial China has rarely been the subject of specific studies because silver exploitation has long been considered of minor importance and traditional sources are scarce. This article is an attempt at filling the research gap of the period from the Song to the late Qing. With a focus on the silver mines of the Southwest and the adjoining borderlands and employing an approach that combines textual analysis with the study of remains and oral histories, it presents a systematic discussion of process steps and traces technological transformations.

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Introduction

Silver smelting technologies in early modern China are relatively unexplored, for the simple reason that sources are exasperatingly scarce. The grand total number of relevant texts with lengths between a single paragraph and a couple of pages amounts to five. Two of these date to about 1200, one to the early seventeenth and another two to the first half of the eighteenth century.

Research on the history of metallurgical technologies has traditionally focussed on origins and rarely extended beyond the Song period (960-1279). Even the authoritative and comprehensive works by Joseph Needham and Lu Gwei-djen, Peter Golas, and Han Rubin and Ke Jun are relatively brief on the silver metallurgy, leaving the centuries from about 1400 largely uncovered. Recent departures broke new ground. Liu Peifeng’s fieldwork-based study on iron and other metal-working sites in southern Shanxi has established that crucible smelting was employed not only for iron, but for lead smelting and silver extraction as well. Liu Siran’s archaeometallurgical analysis of three sites of lead and silver smelting that were worked between the eighth and the fourteenth centuries has achieved the first concrete and specific understanding of the processes at the studied sites. Liu moreover confirms that northwestern crucible technology was established by the fourteenth century.

Focused research on the late imperial period is a desideratum, especially following a re-assessment of the history of silver mining in China. The Song period has long been considered the peak of silver mining in China. In fact, a gradual intensification of silver exploitation is reflected in direct records and the importance of the metal from the ninth century onwards, followed by a massive expansion during the Song, with major mining areas in the highlands of eastern and southeastern China. The Mongol conquest constitutes a rupture, yet silver mining continued, and in the course of the Yuan (1279-1368) underwent a geographic shift to the Southwest. The following centuries have long been regarded as irrelevant. Ming (1368-1644) and Qing (1644-1911) records suggest continuing, but small-scale exploitation, far below the Song and probably not even reaching the scale of the Yuan period. Recent research on material remains in the form of slag heaps and other remains as well as a systematic analysis of scattered records,

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2 Liu (2014) and oral communication with the authors, 2017.
3 Liu (2015). Further research on Song sites is available in Xie and Rehren (2009), and Wang (1983).
however, has outlined a considerable intensification across the Southwest. The beginnings of this development can be dated to the early Ming, with a period of recession during the Ming-Qing transition and a veritable boom in the eighteenth century that lasted into the nineteenth. Total silver outputs of the southwestern and borderland mines between 1400 and 1850 can be reassessed to an order of 30,000 tons. Intensive mining ended in the cataclysmic civil wars of the mid-nineteenth century, which left the region depopulated and impoverished, and mining mostly reduced to a village industry. In the region, industrial transformation began in the late nineteenth century, but remained a slow process.

The new perspective on the history of Chinese silver exploitation reveals two peaks, the first in the Song and centered on the southeastern highlands and across Jiangxi into Hunan, the second in the Ming and Qing and almost exclusively in modern Yunnan province and adjoining areas. Maps 1 and 2, which show the important mining areas of the Song and Qing periods, provide general orientation and visualize geographic shift. The geographic shift may have involved a shift in the exploited ores and the extraction technologies. At present, too little is known about both the ores and the metallurgy for this possibility to be more than conjecture. Silver extraction involved the exploitation of lead and silver ores, with silverized lead ores (galena) constituting a special case. Extraction consisted of smelting in standing furnaces to burn off impurities and to remove most of the rock fraction in the ore as slags. The product of this process step was lead bullion, with the silver alloyed in the metallic lead. In another step, the cupellation, the silver was separated from the lead by oxidizing the lead. The lead oxide (litharge) was typically absorbed into a ceramic or and ash lining, eventually drying up the lead bath and leaving the silver.

Indications on two Song mines suggest that silver and lead ores were exploited at different sites, suggesting that silver mines exploited rich silver ores, while lead was worked separately and independent from its silver content. With the majority of the sites of Song mines not reliably identified, let alone known in their mineralogy, however, conclusions on the evidence of two sites must remain tentative. For four extremely important late imperial mines in Yunnan and the borderlands, the exploitation of silverized galena is documented from modern mineralogical investigations

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or based on slag dumps with lead contents of 30% and more. Although firm evidence of the exploitation of galena, it does not imply the absence of rich silver ores. In fact, the most specific record on the composition of ores, which describes conditions at Kuangshan in the 1840s, an extremely large mine that had been worked for centuries, states that even during the period of decline, 99% of the ore was galena and 1% rich silver ores. While galena ores were worked in many places, it hence appears more suitable to interpret the most common situation in the Southwest as an exploitation of deposits in which silver and lead ores were found in close proximity.

With the geographical shift providing no ready answer on the expansion in scope, technological change requires closer scrutiny. This article is a first attempt at closing the research gap between the fourteenth century

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6 This is the case for Gejiu, Kuangshan, Munai, Maolong in Yunnan and Bawdwin in Myanmar; see Yang and Kim (forthcoming).

Map 2. Important mining areas in late imperial China, c. 1500-1850

and the age of industrial modernization. A targeted exploration has become possible through an ongoing project on late imperial silver mining in southwestern China and the adjoining borderlands of China, Myanmar and Vietnam. In fieldwork on sites and visits to local archives, the authors have accessed materials that are in part new and in part were hitherto not available for research, including descriptions of traditional technologies, modern company records, inscriptions on stone tablets, material remains, and oral histories. The project involved visits to 35 sites in Yunnan, northern Vietnam and in Sichuan that involved surveys of surface remains and interviews with informants (see Map 3). The late and slow modernization in the region was an asset to this research because traditional technologies were in use down to recent decades, providing useful materials for the reconstruction of pre-industrial technologies. In the absence of the possibility to carry out in-depth investigations on sites, the methodology cannot claim to cover archaeo-metallurgy but is mainly historical, though broadened to include less traditional sources. The presentation attempts a systematic reconstruction of technologies and their transformations.
Map 3. Major silver mines in the southwest and the borderlands of late imperial China, c. 1400-1850

The bulk of this article analyses the materials that define the geography and time period from eastern China in the Song period to the Southwest in the nineteenth century. The presentation of the five core texts proceeds chronologically, discussing Song, Ming, and Qing metallurgical technologies, including translations of all key textual passages and the discussion of the terminology. Because the original texts have not been presented in a Western language, this part has the additional purpose of making the materials available for future research. The fourth part pursues additional materials and technologies in materials dating from the late nineteenth century to oral traditions and remains collected in the authors’ fieldwork during recent years.

The concluding discussion of traditions and transformations identifies two major changes in the cupellation process that can be approximately dated to before the early seventeenth and the eighteenth century respectively, both prompting an increase in efficiency.
The Sources

Two short texts describe specific silver mines in eastern China during the late Song. The first is *Yunlu manchao* 雲麓漫鈔 (Random Drafts by Zhao Yanwei) by Zhao Yanwei 趙彦衛 (fl. 1163-1206), a collection of scattered notes printed in 1206. It includes half a page on the Ruiying Mines 瑞應場 in northern Fujian. The second is an excerpt from the local history of Longquan 龍泉 district in the southwestern highlands of Zhejiang province by Chen Baipeng 陳百朋. Little is known about Chen, but since he was active in the late twelfth to early thirteenth centuries, the technologies he records can be dated approximately to 1200. Both Song sources reflect specific conditions in the core mining region at the peak of Song period exploitation.

The only source from the Ming is Song Yingxing's 宋應星 (1587-1666) technological encyclopaedia *Tiangong kaiwu* 天工開物, which was first printed in 1637. The author, who was interested in underlying natural, rational and metaphysical principles, is thought to have mainly recorded technologies in use during his time. He covered the known metals, with specific sections on silver and lead that systematically describe the metallurgical processes. The text contains several references to Yunnan while it does not mention other regions. For this reason, Song Yingxing probably provides a synthesis of late Ming technologies, with a focus on Yunnan.

The core source for Qing period Yunnan is the only surviving monograph on mining and metallurgy, compendium on mining in this province, *Diannan kuangchan tulu* 滇南礦產圖略 (Illustrated Overview of the Mining Products of Yunnan). Wu Qijun 吳其濬 (1789-1847) commissioned the work during his term in office as provincial treasurer and governor-general between late 1843 and May 1845 and had it printed in 1844. Xu Jinsheng 徐金生 (?-c. 1840), is identified as prefect of Dongchuan and credited with illustrating and compiling the work. On account of the briefness of time between Wu's arrival in Yunnan and the publication, Xu presumably was mainly responsible for the content. Moreover, there is a gap between Xu's term in office in Dongchuan and the printing under Wu Qijun's auspices. Little is known about Xu, but he served in four localities in Yunnan. His last tenure was Dongchuan, which is dated from 1837 to 1840 or shortly

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8 *Yunlu manchao*.
9 Wang Lingling identified Chen Baipeng as the original author of *Longquan zhi*. See Wang (2001).
10 This article uses the facsimile reprint reproduced in the *Diaolong* database (2000-present). The still-authoritative study on metallurgy in the *Tiangong kaiwu* is Yoshida (1959).
11 *Diannan kuangchan tulu*.
before.\textsuperscript{12} As Xu left the province before Wu arrived, a collaboration between the two has to be excluded. It appears most probable that Xu compiled the manual in the late 1830s, drawing on existing materials in the provincial mining administration as well as knowledge that he had gathered in Yunnan, with Wu finding the manuscript upon acquainting himself with his tasks in Yunnan and having it printed. The compendium mainly focuses on copper, but included silver. Excerpts from earlier works are evidence of a tradition of collecting materials and of compiling handbooks. The excerpts reach back to Song Yingxing’s chapter on silver and sections from a lost compendium on the copper mines that dates to the second half of the eighteenth century.\textsuperscript{13}

Among the more scattered records of the period, Huang Mengju’s 黃夢菊 (dates unknown) \textit{Diannan shishi} 滇南事實 (Facts on Yunnan) is the most important. An excerpted report that Huang submitted to the provincial government during his term in office at Huize 會澤 district in northeastern Yunnan from 1843 to 1846 presents conditions at the Kuangshan 矿山 mines.\textsuperscript{14} Roughly contemporaneous with Wu Qijun’s work, Huang Mengju provides supplemental and corrective information. Wu Qijun and the other sources dating between the mid-eighteenth to the mid-nineteenth century record the technologies during the most intensive period of exploitation in Yunnan.

The overall scarcity of materials and the often occasional nature of the texts may appear surprising in view of the massive body of Chinese literature. Vagaries of transmission, Confucian attitudes, and structures of the late imperial administration contributed to a situation that greatly hampers text-based research in the history of technology of China. Over the course of time, texts written or printed on paper inevitably get lost unless they happen to be carefully preserved or re-printed. In these protective

\textsuperscript{12} For biographic information on Xu Jinsheng, see Yu (1925) \textit{juan} 19, p. 13 and \textit{Dongchuanfu xuzhi}, \textit{juan} 1, p. 471. Xu took leave to mourn his father before his term in office ended and died during the journey home.

\textsuperscript{13} The earlier compendium compiled by Wang Chang 王昶 (1724-1806) was titled \textit{Tongzheng quanshu} 銅政全書 (Complete materials on the copper administration) and its date of publication is unknown. Since Wang Chang served as an emissary to the Southwest during the 1760s and 1770s, his work probably reflects the situation up to 1770. A key section reproduced in \textit{Diannan kuangchan tulue} is a series of reports that provide information on technical and organizational issues by local officials; unfortunately, also undated. The section titled \textit{Zixun gechang dui} 各廠對 (Information Provided by the Mine [Officials]) contains questions and excerpts from one or several responses, recording specific situations in separate mining areas.

\textsuperscript{14} \textit{Diannan shishi}, pp. 58-66. On Huang’s turn in office, see \textit{Dongchuanfu xuzhi}, p. 472.
measures, institutions and individuals prioritized texts of high cultural standing, particularly political history and high literature. For all we know, a technical literature may have existed during the Song period, but only fractions survived in a geographic source and in the personal notes of a scholar. Confucian agriculturalism stipulated that farming in general and the production of grain in particular was the foundation of “nourishing the people” and hence of the state and its ruler. This basic tenet implied that all other economic activities were potentially distracting peasants from tilling their fields and wasting resources. Partly in reaction to the Mongol conquest and a rejection of both the more openly commercialized Song and the extractive Yuan periods, late imperial attitudes became orthodox, at least in the representations of imperial rule and on the surface. The social and economic realities under this veneer soon returned to a thoroughly commercialized life. The observation of an increasingly imaginary simplicity and orthodoxy led to official representations that selectively governed and represented the economic activities and practices on the ground. The imperial orthodoxy and the structures in education and career opportunities through the state examination system also influenced private writings of the educated elite. Scholarly authors could express a suitable interest in mining, such as in the linguistics of special terms, the hard life of the miners, or social problems cause for local societies, but a expressing a focussed interest was morally suspicious and not printable. Song Yingxing’s broad interest in technologies was a personal venture that he was able to pursue with the support of socially superior mentors in official positions. Dagmar Schaefer’s biographical research had demonstrated, however, that he was not part of a network and that even the two most supportive mentors failed to see a purpose in *Tiangong kaiwu*.

The inherently problematic nature of mining led to a layered administration. In the Ming, silver mines in the Southwest were supervised by eunuchs dispatched directly by the throne and thus no longer part of the formal administration. In the Qing, a provincial mining administration is known to have existed in Yunnan province, but the actual operations of this institution were below the formally existing structures of the provincial government, run by staff employed privately or informally. Wu Qijun’s compendium is the only surviving work left by this institution, while an earlier handbook was lost and no archival materials survived the end of the dynasty. *Diannan kuangchuan tulue* reflects the knowledge of administrators. For the purpose of supervising the mines, they needed some technical knowledge, covering the terminology and a grasp of the processes. An

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15 See Will and Wong (1991), chapter 1 on this tenet and its implications for state tasks in food security.
actual understanding of the technologies and their practical application, however, was not required. At the same time, the government had no inclination or ability to operate its own mines. In the absence of competition, mining operators did not need to practice particular caution to safeguard technologies. For this reason, the focus on terminology provides valuable concrete information, as well as a tool for pursuing specific technologies in modern materials. As mentioned above, mining operators certainly kept a documentation that may have recorded technologies. As business records, however, these were not produced to be preserved and vanished with the end of the operation.

The sources of the late nineteenth to the early twentieth century as well as recent materials on traditional technologies reflect technologies in the Southwest through the period of modern modifications. During the early period of modernization, four authors with technical knowledge recorded silver mining in Yunnan. In 1871, Émile Rocher (1849-1910), who had some metallurgical knowledge, visited mines in Yunnan. Due to privileged contacts with both administrators and entrepreneurs, his account is particularly valuable for the Gejiu Mines 个旧 in the south of the province. In 1901, Audémard Leclère visited Huili 会理, Dongchuan 东川, and Gejiu. In 1902, Song Gengping 宋賡平 (dates unknown) published materials and reports on mines to promote the industry and aid development of specialized mining academies in Sichuan. His observations regarding the mines date to late 1890, while his sources for the traditional technologies are unclear. The Japanese engineer Yamaguchi Yoshikatsu 山口義勝 (dates unknown) was dispatched to northeastern Yunnan to assist with modernization at the end of the Qing dynasty, where he also observed the smelting technologies employed at the Kuangshan Mines.

For additional materials, the authors, together with Li Xiaocen 李晓岑, Liu Peifeng 刘培峰 and Vu Duong Luan, undertook seven fieldwork trips to historic mining sites in Yunnan, Sichuan and Vietnam between 2011 and

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18 On the silver mining administration of Yunnan in the Ming, see Yang Shouchuan (2014), pp. 65-66; on the layered administration and the obfuscation in the official records of the Qing, see Kim and Yang (2019).
19 Rocher (1879).
20 Leclère (1901) and (1902).
21 Song (1902). Song held an official rank and the preface mentions that he spent 18 years abroad studying the mining industries of Europe and America (ibid., juan 1, p. 3b). Song recommends the use of traditional technologies and gradual modernization. The book was probably printed to be used as a textbook in the newly established mining schools in Chengdu and Chongqing.
22 Yamaguchi (1912).
2018. Local specialists as well as mining engineers provided much valuable information on sites, historical techniques, ores and slags. He Junzhong (b. 1949) and his son He Xiaoli (b. 1976) in particular, took two days in 30 to 31 March 2011 to introduce us to the Fulong 富隆 mines and their rich practical experience in the re-exploitation of slags and historic mines.

In order to reflect the geographic shift from eastern China to the Southwest and the long periods of silence as well as to account for the greater detail of the later records, the sources are discussed in four groups, namely the Song period and the eastern mining centres, the late Ming with a probable but not exclusive emphasis of the Southwest, the late eighteenth to mid-nineteenth century, and the late traditional period from the late nineteenth century onwards, with the latter two groups exclusively focusing on the Southwest. For each group, the core sources are translated and discussed, drawing on later materials where they contribute to our understanding of the process or the device. The discussion of modern materials is more selective, focusing on additional information and technological modifications.

**Zhao Yanwei and Chen Baipeng, c. 1160-1200**

Zhao Yanwei’s short description of the Ruiying 瑞應 Mines specifies their location as 240 li from the county seat of Songxi 松溪 and in operation from the 1130s to the 1170s. In the space of 338 characters, he relates the mines’ history over some three decades, including the work in the mines and the distribution of the income generated. The passage on the mines and smelters covers the workings, extraction processes, and key terms:

> The method of extracting the silver is this: where the black paths show on the rock walls, these are silver veins, and holes are dug following the veins, large enough for a man to enter. These are driven over ten zhang (c. 32 m) deep into the mountain; the men see by the light of their own candles and extract the silver ore in broken up rock. This is ground by pestle and mortar, then loaded in a mill, sieved finely through gauze, and washed in sieves immersed in water. The yellow is stone and discarded,


24 Present-day Songxi county in northern Fujian province.
the black is silver [ore]. This is shaped into lumps with flour and entered into the lead. It is forged by fire into large plates, which are entered into the government store. Then over two to three days, these are again smelted into broken silver. ... [The ore] usually passes hands six times, which the miners call ‘passing through the pond.’ These [treatments] include ‘passing through the water pond,’ the ‘lead pond,’ and the ‘ash pond.’

The description evidently is of underground mining that targeted a blackish silver ore, possibly argentite. The ore was meticulously ground into powder and separated from the gangue fractions by flotation. The description of the smelting indicates two main steps. The first involves using flour paste to shape the ground ore into lumps, which were then smelted to produce plates of lead bullion. In the second step, silver was obtained from these plates. In the absence of further description, the smelting steps can only be approximately identified by the technical terms. The first two of the four recorded terms refer to ore dressing. ‘Passing through the pond’ and ‘passing through the water pond’ can be identified as crushing the ore in mortars and to ore washing. The ‘lead pond’ clearly refers to the production of rich lead, while the ‘ash pond’ identifies cupellation, with the oxidized lead absorbed into the ash. The mention of six treatments with only three named steps is slightly mystifying. It appears possible that the omitted steps were the mining itself, possibly a roasting process, and the grinding in mortars.

In his account of the extraction of silver in Longquan district, Chen Baipeng describes four process steps following the extraction of the ore. Ore dressing is presented as a specialized, labour-intensive process:

All ore rock in any quantity is taken into the pounding workshop, where it is pounded extremely finely into what is called ore powder. In the next step, water is used to fill a large vat and the ore powder is thrown in, then stirred several hundred times in what is called ‘stirring the glue.’ The ‘glue’ separates into three components: the parts that float on the surface are called ‘thin glue,’ the parts that stay suspended in the water are called ‘plum sand,’ and the parts that sink to the bottom are called

coarse ore flesh. To treat the ‘thin glue’ and the ‘plum sand,’ a basin with a pointed bottom is used, which floats in the washing pond. Through repeated flotation and discarding, the uplifting current takes the coarse matter away, leaving only the finest behind. To treat the coarse ore flesh, a wooden basin resembling a small boat is used, and flotation and discarding of the materials is utilized in the same manner. As a rule, one should remove the rock and keep only the true ore. The sediment that remains in the vat, which sparkles visibly, is called ‘ore flesh.’

礦石不拘多少，采入碓坊，舂碓極細，是謂礦末。次於大桶盛水，投礦末於水中，攪數百下，謂之攪粘。凡礦中之粘分三等，浮於面者謂之細粘，桶中者謂之梅砂，沉於底者謂之粗礦肉。細粘與梅砂，用尖底淘盆，浮於淘池中，且淘且汰，泛飏去粗，留取其精英者。其粗礦肉，則用一木盆如小舟然，淘汰亦如前法。大率欲淘去石末，存其真礦。以桶存貯，璀璨星星可觀，是謂礦肉。

The very fine crushing reflects a thorough separation of ore and gangue. The text does not specify whether it was performed manually with rocks or hammers or by water-driven pestles. The latter is possible, as the transmission of the continuous, circular motion of a water wheel to a linear, back-and-forth movement was well established in the heartlands of Song China. The mention of a building suggests permanent installations. The second step in Chen’s account clearly describes roasting:

[The dressed ore] is mixed with rice gruel to form lumps the size of a fist. These are placed in rows on charcoal and then covered with 1 chi (32 cm) of charcoal. The fire is lit at daybreak and lasts until the ninth hour (c. 3-5 pm), when it is extinguished and allowed to cool. The [product] is called “kiln lumps.”

26 Shuyuan zaji, pp. 175-176.

27 The first explicit description of water-driven mallets used in mining dates many centuries later, to the late seventeenth century. Tian Wen 田雯 (1635-1704) reports on these machines for the “Zinc of Kaili” (Kaili zhi qian 凱里之鉛) (see Qianshu). The name Kaili has not been localized, thus the mine remains unidentified. The character qian 鉛 means lead, but, when metallic zinc became known, it was called woqian 倭鉛 (dwarf lead) or baiqian 白鉛 (white lead), and lead came to be differentiated as heiqian 黑鉛 (black lead). Since zinc mining in Guizhou had reached a considerable scale by the seventeenth century, the qian in ‘Kaili zhi qian’ presumably refers to zinc mines.
The roasting indicates the exploitation of sulphide ores and possibly the presence of arsenic. The forming of the ore into lumps may have been required for handling and helped to reduce the loss of small ore fractions. The use of rice gruel, which corresponds to that of flour recorded by Zhao Yanwei, could have been simply as a glue or served to enhance the reduction of oxidized metals in the ore. The latter purpose is recorded in the context of copper smelting. Here, rice water or gruel was used for quenching copper plates, with the effect of enhancing the red hue of the metal.

The third step in Chen’s account describes the smelting of lead and roasted silver ore to produce a cake of rich lead:

In the next step, charcoal is lit in the ping-silver furnace, lead is thrown in, and the hands working the ‘bellow drum fans’ must not stop. Now the lead, which by its nature absorbs silver, collects in the furnace bottom, leaving only frothy slags floating on the surface. This is repeated several times until the ‘furnace pumpkin’ emerges from the flames and the slags are ripped off the surface. When the smelting is completed, it takes a long time to extinguish the fire using water. Now silver and lead have become one, this is called ‘lead tuo.’

The description records a special name of the smelting furnace, and the adding of lead, while making no explicit mention of the silver ore. The description of the repeated process of lead collecting in the bottom and frothy slags forming on the surface suggests that the sprinkling of ore into the lead melt was repeated several times, leading to the absorption of the silver into the metallic lead and impurities forming slags that were raked off. The product is identified as lead bullion; although the term tuo ‘camel’ might be derived from mituoseng or litharge, which is discussed below.

The terminology used by the Song authors appears to be consistent with that known in late imperial period. The late usage differentiates two structures used in firing processes, yao ‘kiln,’ which usually appears in the context of ceramics and charcoal burning, and lu ‘furnace,’ which

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28 Shuyuan zaji, p. 175.
29 Diannan kuangchan tulue, juan 1, p. 9.
30 Shuyuan zaji, p. 176.
indicates a standing furnace. By this reading, Chen Baipeng identifies the roasting kiln as a low structure and the ping furnace as a standing furnace.

The ‘bellow drum’ (baigu 輪鼓) is clearly a bellow, but its specific identification is uncertain. Bai in its original meaning designates a leather bellow, but could be generalized to refer to devices invented later, such as bellows that worked with flaps or pistons. Gu could also be used as a very general term referring to a wind machine, or a descriptive terms referring to a drum-like shape. The device may be tentatively identified as a leather bellow in the shape of an accordion or any bellow if a generic term. It was evidently worked by hand.

The fourth step in Chen’s description is the cupellation:

In the next step, the best locally available furnace ashes are used, and, in accordance with the size of the lead camel, a shallow ash nest is formed. The lead camel is placed in it and surrounded by several layers of charcoal. The fire must be fanned constantly. At first, lead and silver are mixed, floating in the liquid melt in the ash nest. One sees fumes rising and flying away from the surface of the melt and, after a long time, they become thin, while snow-like froth forms on the bubbling surface. When the snowy froth ends, [the melt] suddenly turns clear. A little later again, the colour changes to muddy from one side; this is called “turning the nest.” This shows that the silver is ready, while the smoke and the froth indicate that the lead vapours have not yet gone. By its nature, lead fears ash, this is why ash is used to catch the lead, it goes into the ash lining and only the silver remains. Between the fifth and seventh hour (c. 7 am-1 pm), the silver becomes visible. The lead that is absorbed by the ash is the mituoseng that is used in medicines.

The ‘ash nest’ (huichao 灰巢) was tailor-made for each lead cake. The description suggests an open structure subjected to an airflow from above. The ‘fanning’ does identify a fan but is a general term that could refer to

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31 Shuyuan zaji, p. 176.
any wind machine. As there is no description of the lead oxide being raked off, it seems that all oxidized lead was absorbed by the hearth, leaving the silver ingot. In addition to the ‘ash pond’ recorded by Zhao Yanwei, another author of the period, the passage mentions the ‘ash nest.’ Separation by ‘ash-blowing’ (huichui 灰吹), therefore, can be established as the standard process around 1200. Since earlier sources record ceramic linings, the use of ash appears to be an innovation dating between the tenth and the twelfth century.

The ash-blowing lasted for almost a day. The process closely resembles haifuki 灰吹 ‘ash-blowing’ as documented in early modern Japan in historical illustrations, as well as by archaeological research. The technology is known to have been introduced to Japan from Korea in 1533, but we have no records that reflect more than the existence of silver mining and smelting in Korea during the early Joseon period.

*Mituoseng 蜜陀僧 ‘Amitaba monk’ was the lead absorbed into the ash lining. The first record of the substance appears in a pharmaceutical reference work dating approximately two centuries earlier.* The name remained in use and it likely refers to litharge or lead oxide. The medical use is clearly documented, while other applications uses, especially in glazes and as a pigment, are not recorded but highly probable in the period, during which large scale silver exploitation coincided with a great expansion in urbanization and ceramic production. Chen’s record suggests that there was a market for both the silver and litharge.

The processes described reflect the exploitation of rich silver ores and indicate that the lead was procured from other sites. The extensive dressing of the ore suggests that worked ores had to be separated from problematic gangue fractions and that the resulting concentration of silver was high, making the labour input viable. While the accounts appear to describe a small-scale process, Song records and remains document a highly intensive

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32 Pingzhai wenji.
34 Kobata (1965); Todd (1998); and Carré (2013).
35 Japanese records identify the year 1533 and the Korean specialists, but Korean records are vague. The records of the Goreo period (918-1392) are silent on mining, and Joseon (1392-1909) records are extremely scarce, the only likely mention of cupellation by ash-blowing dating to 1407, where there is a reference to producing silver by chwilyeon 吹煉 ‘blowing-refining’: see Joseon wangjo sillog 朝鮮王朝實錄 (Annals of the Joseon Dynasty), Taejong sillog 太宗實錄 (Annals of Taejong), chapter 14, p. 36B.
36 Su Song’s 陳達 (1020-1101) Bencao tujing 本草圖經 (Illustrated pharmacopoeia), published in 1061, has not survived, but is quoted in Chongxiu Zhenghe jingshi zhenglei beiyong bencao. The latter work survives in a thirteenth century imprint. Tang Shenwei is known to have been active in the late twelfth century.
exploitation of silver. It would appear that Song period silver mines focused on high-grade ores and expanded in scale by increasing the number of furnaces and hearths.

Song Yingxing, c. 1600-1630

Tiangong kaiwu records silver and lead mines in various parts of Late Ming China. Song Yingxing refers to Yunnan mines at several instances and specifically pointed out that this province produced twice as much silver as all eight other provinces that possessed silver mines put together. He moreover specifies that silver-lead ores were predominant in Yunnan.\(^{37}\) The overwhelming importance of the Southwest confirms the shift in silver mining following the Mongol conquest of this region.\(^{38}\) Song’s friend and mentor Tu Shaokui 涂紹煃 (1582-1645), who served in high positions in Sichuan, Guizhou and Yunnan from 1623 to about 1634, developed an interest in mining and is the most likely source of information on the Yunnan mines.\(^{39}\) Moreover, Song accompanied Tu as a private secretary and wrote at least the sections copper mining during his stay in Yunnan.\(^{40}\) For these reasons, we expect that Song mainly describes contemporary technologies in use in Yunnan, certainly for the treatment of lead-silver ores and probably but not necessarily exclusively for other processes.

Song Yingxing records conditions and processes that greatly differed from the known Song mines. The most common situation at the mines he describes was the working of lead-silver ores or of lead and silver ores in the immediate vicinity. The exploitation of silver ores had become the exception. The account records underground mining, with the first mention of timbering.

\(^{37}\) Tiangong kaiwu, juan xia, p. 4b and 22a.

\(^{38}\) Lee (2012), pp. 262-263, quotes a Yuan period record according to which Yunnan silver mines exceeded the productivity of all other mines in the empire together. Based on tax quotas, he estimates total outputs of the Yuan and Ming periods at 2500 tons, cautioning that the reconstruction is based on incomplete data. Hillman et al. (2015) provide new evidence on a steep increase in silver mining in the Dali region based on sediment cores of Erhai Lake.

\(^{39}\) Schaefer (2011) pp. 245-247. We would like to thank the anonymous reviewer to have alerted us to Tu Shaokui’s role in Song Yinxing’s work.

\(^{40}\) The transmission of the chapter on silver is documented in Wu Qijun’s Diannan kuangchan tulue and by Ding Wenjiang 丁文江 (1887-1936), who found the chapters in an edition of the provincial gazetteer in 1914 (see his postface to the 1929 reprint of Tiangong kaiwu in Tiangong kaiwu 2002, p. 422).
Song differentiates four kinds of silver ores:

All that transforms into silver is called jiao 矼, very small granules are called sha 砂 (sand), that with twig-like branching shapes on the surface is called mao 鈃 (nails), and that which is enveloped in rock is called kuang 矿 (ore). The ore is similar in appearance to coal with a base of rock, yet not altogether black. It occurs in several grades of richness.

凡成銀者曰礁,至碎者曰砂,其面分丫若枝形者曰鉚,其外包環石塊曰礦。...

The differentiation by colour, shape and structure does not permit clear identification. The interpretation of jiao as the umbrella term designating all silver ores with three sub-types is also possible. Compounds referring to ore in general that appear elsewhere in the text are jiaosha 矼砂 (charcoal rock and sand) and maosha 鈃砂 (nails and sand), identifying ore in large and small pieces. Since the term jiao commonly refers to coal, it could identify the highest grade ore as nearly black, making argentite probable.

Song Yingxing briefly mentions ore dressing as a process that involves sorting, cleansing, and washing by flotation, while roasting appears in none of the metallurgical processes that he describes. Because he emphasizes that silver mines had to be driven in for months to reach ore veins and the technology is firmly documented four centuries earlier, an omission of a process step that appeared less interesting is possible. However, as direct lead extraction was possible, if high-grade galena ores from the oxidized or cementation zone were worked, there is a possibility that direct smelting was practices in some mines.

The most detailed part of the account describes two smelting processes. The smelting furnace and process is presented first:

The furnace is built from mud in the shape of a high column base, over 5 chi (c. 1.6 m) high, the bottom is lined with porcelain sherds and charcoal ash. A furnace is loaded with 2 dan (140 kg) of ground silver ore. 200 jin (c. 120 kg) of chestnut wood charcoal are used, surrounding, penetrating, and supporting [the ore]. Immediately attached to the furnace is a brick wall, over 1 zhang (3.2 m) wide and high. The bellows are installed behind this wall and worked by 2 to 3 people. A pipe

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41 *Tiāngōng kāiwǔ, juàn xià*, p. 5a.
42 Han and Ke (2007), p. 317, defines the required lead content as upwards of 65%.
takes the wind to the furnace. The wall serves as a screen against the heat, protecting the people at the bellows. When the charcoal is consumed, more is added using long iron prongs. When the force of the fire and the wind have reached the right strength, the ore melts and forms a lump. At this time, the silver is hidden in the lead and has not yet separated. It is estimated that, from 2 dan of ore, 100 jin (60 kg) of lead is obtained.

Figure 1. Illustration of a lead-smelting furnace from the Tiangong kaiwu

SOURCE: Tiangong kaiwu, juan xia, p. 5a-b.
Song Yingxing provides the first description of lead smelting in China. The furnace is described as a structure that was some 1.5 m high, with a lining of porcelain sherds and charcoal ash in the hearth. A wall, over 3 m in height and width, screened the men who worked the bellows from the heat. The ventilation pipe from the bellows passed through the wall to the interior of the furnace at about halfway up its height. The furnace load apparently consisted of 120 kg of charcoal and 140 kg of ore. The illustration in Figure 1 shows a relatively low, square furnace, a high screening wall, and a square piston bellow, with two workers visible.

Cupellation in silver separation or ‘toad furnaces’ is described as the second step:

Once cooled down and solidified, [the rich lead] is taken out and placed in the silver separation furnace (also called the toad furnace), which is enclosed with pine charcoal and has an opening for observing the fire. These furnaces use either wind-boxes or crossed fans. When the fire has reached the right temperature, the lead sinks down, forming the bottom of the furnace (this bottom looks like a ‘hunchbacked monk,’ and it is smelted again in a different furnace, becoming ‘carrying pole lead’). Many willow branches are stuck in through the furnace openings and burnt; these cleanse the lead vapours, so that the “worldly treasure” can take its shape. The silver that emerges is called “raw silver.”

The lead is absorbed into the furnace bottom, referred to as the tuoseng 陀僧 ‘hunchback monk,’ which is easily identified as shorthand for mituoseng and, hence, of litharge, while the biandan qian 扁担鉛 ‘carrying pole lead’ is defined elsewhere as metallic lead that contains no silver. “Worldly treasure” identifies silver as an unminted money.

According to this description, cupellation required pine charcoal, which was packed around the lead cake in a special furnace. With the use of bellows, the lead became litharge, which could be smelted again to obtain metallic lead, and willow branches were stuck into the furnace for a purpose that is unclear. The seemingly straightforward description, however, loses clarity under closer scrutiny. Song mentions no ash lining of the

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44 Tiangong kaiwu, juan xia, pp. 5b-6a.
45 Ibid., juan xia, p. 22.
hearth. Moreover, the shape of the furnace is unclear. The term ‘furnace’ suggests a standing structure, with openings in the side for supervision and the insertion of the willow branches, while the name ‘toad furnace,’ if referring to the shape, would identify a squat structure with a rounded top. The accompanying illustration adds to the confusion, showing an open, basin-like structure (Figure 2).

Figure 2. Illustration of a cupellation hearth from the Tiangong kaiwu


The conflicting information given in the sources regarding ventilation contributes to the confusion regarding the furnace’s shape. The text records the use of fengxiang 風箱 ‘wind boxes,’ which were piston bellows in widespread use by the time of Song Yingxing. The texts also record jiawsha 交箑 ‘crossed fans,’ a slightly cryptic term that most probably refers to wooden flap bellows mounted in a pair to provide continuous airflow. Piston bellows consisted of a hollowed tree trunk or rectangular box with airtight lids at both ends and two air outlets near each end. The device was

46 We would like to thank Liu Peifeng for identifying this technology that was widespread in iron metallurgy. See Liu Peifeng et al. (2017).
worked using a rod that fitted through the holes at either end, on which a plate valve with rims covered in feathers was mounted within the trunk or box. An air channel received an inflow from both ends and directed them to the outlet in the centre, producing a continuous air stream. Figure 1, the illustration of lead smelting, shows a large piston bellows in operation behind the wall.

Flap bellows consisted of a wooden box, with the airflow generated by a large wooden flap attached by hinges to the top of the box. By moving two flaps alternatively, a relatively continuous airflow could be achieved. This type of bellows is shown in Figure 5 (see p. 39).

The accompanying illustration, however, shows two men working hand-held fans. The air stream this could have produced could not have been sufficient for the size of furnace depicted, and working unprotected from the emanating heat appears highly hazardous. We conclude that the illustration was a later addition that interpreted the text rather than providing factual visual information, representing ‘crossed fans’ as fans. The furnace in the illustration, therefore, similarly has to be regarded as a generic representation only. We therefore expect the toad furnace to have been a closed structure with small openings. The furnace hearth appears to have been loaded with a lead cake and charcoal packed around it, presumably on an ash lining, as in the “ash nest” and operated under ventilation.

Song Yingxing adds that certain mines in Chuxiong prefecture added metal lead instead of using lead present in the ore:

The [ore] of Chuxiong is, however, different, for the lead vapour in the ores extracted from these mines is very low. Therefore, they have to buy lead from other places to aid their smelting. For each 100 jin of ore, they first place 200 jin of ‘lead base’ into the furnace and smelt it into a lump while working the fans. This is then placed into the toad furnace where the lead sinks down and the silver collects, by the same method [as described above]. This is how ‘worldly treasure’ is produced, there are no other ways for providing it.

The process is similar and cupellation specifies the use of “toad furnaces.” The specification that 120 kg of lead were used for treating 60 kg of silver ore suggests rich lead cakes of at least 150 kg, while the cakes produced in the ping-furnaces weighed only 60 kg. The size of the lead cakes

47 Tiangong kaiwu, juan xia, p. 6a.
suggests that toad furnaces could treat larger loads than would have been probable for the open "ash nests."

A clear technological difference between the eastern Song mines and the Yunnanese mines of the late Ming were the shift from “ash nests” to “toad furnaces” in cupellation. Transformations in ventilation and furnace sizes is a possibility. Both wooden flap and piston bellows were in use in the Song, although clear evidence in silver smelting is missing. Song Yingxing thus is the first to record these ventilation devices as the standard by the late Ming. In the absence of other materials, the efficiency of furnaces and ventilation cannot be assessed.

**Wu Qijun and Huang Mengjun, c. 1750-1850**

The only surviving systematic account of silver and copper mining and metallurgy dates two centuries after Song Yingxing. Wu Qijun’s compendium of 1844, together with Huang Mengju’s description of the Kuangshan mines in northeastern Yunnan of the 1840s and reports on the Baiyang 白羊 Mines in western Yunnan, which are quoted in Wu Qijun from a lost compendium of the Yunnan mining administration and dating to the second half of the eighteenth century, as well as later materials on the region, permits a relatively detailed reconstruction of the technologies in use in the Southwest during the mid-eighteenth to mid-nineteenth centuries.

Wu Qijun provides unmistakeable evidence that Song Yingxing’s work on silver metallurgy survived in Yunnan and was used by the mining administration. *Diannan kuangchan tulue* reprints the full text with some annotations on contemporary terminology and technologies.48

**Ores**

Records on the ores worked for silver indicate an important difference in their treatment. Wu Qijun and Huang Mengju group the ores as ‘frying ores’ (*zha kuang* 炸礦) and ‘great fire ores’ (*dahuo kuang* 大火礦) or ‘bright ores’ (*ming kuang* 明礦). Both texts specify that ‘frying ores’ could be directly cupellated, while ‘great fire ores’ had to be smelted for rich lead first.49 In addition, Wu Qijun records copper-silver and silver-copper ores that were exploited at a few mines and required special treatment. These

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48 *Diannan kuangchan tulue*, juan shang, pp. 25-27.
49 *Ibid.*, juan shang, p. 6a; and *Diannan shishi*, p. 61a. The use of the character dong 窟 (mine) in Huang Mengju is an error, probably of gong 窟, which is an alternative word for kuang and probably had the same pronunciation in the Southwest.
ores nevertheless were of special interest to the administrators because their main task was ensuring the supply of copper for the imperial mints.

The ‘frying ores’ were rich ores. According to Wu Qijun, the highest grades yielded 1-7 liang peizi 鼠子 and could reach 8 liang peizi. The peizi 胚子 was an assaying unit, defined for the fen 分 (0.01%) of a peizi as 0.01 liang 两. Given in liang, it identifies the silver yield in liang per jin and hence converts to 6.25%-43.75% and 50% respectively. 50

Huang Mengju reported far lower yields for the Kuangshan Mines. Good ores yielded between 0.3 and 0.5 liang per jin or just under 2% to 3%, and the very best 2 to 3 liang, or 12.5% to almost 19%. 52 Silver mining at this site appears in the written records only in the early nineteenth century and appears to be negligible in scope, while a zinc mine of some importance is documented from about 1740, and lead exploitation seems probable. Local oral traditions, however, date the beginnings of the mines to the Ming period, and lead slags that have been re-exploited from the 1950s amount to 1.3 million tons. 53 Despite the uncertain written record, there is no doubt of intensive exploitation over several centuries, as well as and the parallel working of lead, silver and zinc ores in the later phases of the mines. Due to the long-standing exploitation by the 1840s, low silver content in the ore is to be expected.

For the ‘bright ores,’ Wu Qijun records 1 peizi or 625 g/t as the minimum silver content worth exploitation. 54 Huang Mengju records extractable yields of 1000 to 3000 g/t, but also rich lead with minimum contents of only 300 g/t. 55

The only recorded proportion of rich silver ores and silverized galena occurs in a memorial that Lin Zexu 林则徐 (1785-1850) submitted to the throne in the late 1840s in the context of substantial reforms in the mining regulations. He stated only 1% of all extracted ores were rich ores, while 99% were lead ores, and details that the silver content in the lead bullion

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50 Diannan kuangchan tulue, juan shang, p. 6a. The standard liang weighed about 37 g and the jin of 16 liang 592 g.
51 Ibid., vol. 1, p. 6b.
52 Diannan shishi, p. 58b.
53 Yamaguchi (1912) records oral traditions on the history of the mines in 1912 or shortly before. For the scope of the historic workings and the slag dumps, see Yunnan Huize qianxin kuang (1992). The historic zinc smelters were at a different location. For a discussion of the records and fieldwork by the authors, see https://www.zo.uni-heidelberg.de/sinologie/research/epm/08_kuangshan.pdf (accessed 21 January 2019).
54 Diannan kuangchan tulue, juan shang, p. 6a.
55 Ibid., p. 59a.
was at best 4.3 peizi (2,188 to 1,875 g/t) and often merely 1.1.5 peizi (625 to 938 g/t).56

Lin provides these data in an argument for lifting the ban on trading in metallic lead for Yunnanese mines. As Lin’s other data is similar to Huang Mengju’s account, Huang is the probable source. The supposed averages of Yunnan silver mines hence in fact reflect the situation at Kuangshan, which were a case where operations were maintained beyond the exploitation of silver ores by the combined working of zinc and lead as well. Hence, the ratio of 99:1 for galena to rich silver ores and the minimum economically viable silver yield of 625 g/t certainly represent the very lowest possible values.

‘Frying’ and ‘bright’ ores were separated and processed differently. Wu Qijun and Huang Mengju record four process steps for ‘bright ores’ or galena, with variants for rich ores and for copper-silver ores. Treatments of the former consisted of washing and crushing, roasting, smelting for lead bullion, and cupellation. Rich ores were dressed, but apparently not roasted, and cupellated with lead or lead bullion. Cupellation of lead bullion and rich ores employed different cupellation furnaces. Copper-silver ores were dressed and roasted, then smelted for ‘ice copper’ (bingtong 冰銅) or copper dross, an unmelted mixture of copper, lead, and some silver with other impurities. The dross remained in the furnace, while the silverized lead was tapped. The lead contained most of the silver and was cupelated, while the ‘ice slag’ had to undergo several rounds of roasting before it could be smelted for copper. In the following, this paper omits the metallurgy involved in treating copper-silver ores.

Ore dressing

Diannan kuangchan tulue records ore dressing in the description of copper mining:

The method of treating the ore: the ore is mixed with sand and rock; it first has to be pounded finely and then washed with sieves under water, so that the lighter sand and rock are carried off with the water. The ore granules that settle in the sieve are suitable for roasting and smelting.

掣礦之法，礦雜砂石，必先細碎，用篩於水內淘洗，使砂石不輕浮隨水而去。礦砂沉重，聚於篩中，以便煎煉也。57

The description appears in the section that dates to the second half of the eighteenth century. An illustration in the same work, which probably dates to the time of printing, provides additional information (Figure 3).

56 “Chakan kuangchang qingxing shixing kaicai shu,” p. 11.
57 Diannan kuangchan tulue, juan shang, p. 39b.
Figure 3. Illustration showing the sorting, crushing, and washing of ore, Xu Jinsheng 徐金生, c. 1840.

SOURCE: Diannan kuangchan tulue, unpaginated illustrations.
The illustration shows a figure sorting ore at the mine entrance by breaking off large pieces of gangue with a hammer. At the bottom of the slope, another person is shown ‘floating off gangue’ (taohuang 淘塃) by dipping a sieve into flowing water. In the foreground, a person is ‘washing the ore’ (xikuang 洗礦) using a sieve, but whilst working in a still reservoir. The illustrations in combination with the inscription thus identify two flotation processes, the first in flowing water, presumably to remove light gangue fractions, and another in still water, presumably relying on the worker’s movement and used to remove fine fractions.

**Roasting**

In sources of the eighteenth and nineteenth centuries, roasting is consistently referred to as duan 鍛 ‘forging’ or duan 煅 ‘firing’ and thus differentiated from smelting processes (lian 煉 or jian 煎). Huang Mengju specifically records roasting as the standard first step in the treatment of lead-silver ores. As a process to burn off sulphides, arsenics and other contaminants that hindered smelting, the standard preparatory treatment shows that exploitation concentrated on the cementation and sulphurized zone.

**Lead smelting**

Huang Mengju describes the smelting of ‘great fire ores’:

The great fire ore contains much lead, but little silver, yielding only 0.003 (0.1 g) to 0.005 (0.2 g) liang silver per jin (592 g), and, moreover, the silver is hidden in the lead, it is dry by nature and produces a thick melt; therefore, it has to be roasted by being placed on brushwood in kilns, then it is loaded into furnaces for smelting. Large furnaces will smelt 10,000 jin (5.9 t) of great fire ore, while small ones smelt 3,000 to 4,000 jin (1.8-3.8 t). The ore transforms and liquefies, and the cleansed liquid becomes lead.

Lian 銅 and qian 銀 are both pronounced yuan in Yunnanese and both refer to lead. Lead and zinc used to be differentiated as black and white lead (heiqian 黑銅 and baiqian 白銅), with qian in the Southwestern usage commonly used for zinc. The lead-silver ores recorded by Huang Mengju

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58 Diannan shishi, p. 58b.
59 Ibid., p. 61a
yielded 200-300 g/t of silver, suggesting galena with a silver content in fact below the threshold of economic silver extraction. According to an early twentieth century work on mining geology, "primary galena has a maximum silver content of 500 g/t, with the silver evenly distributed," whereas, "galena in the cementation zone can contain 10 and more kg/t, with the silver deposited in cracks and gaps in the galena. Rich silver sulphides are also part of the cementation zone and disappear in deeper layers." The galena ores worked at Kuangshan suggest that after centuries of exploitation silver had become a secondary product in an operation that mainly relied on exploiting lead and zinc.

The dimensions of the furnaces were large, with ore loads ranging from 1.8 tons to 5.9 tons. Wu Qijun presents the treatment of copper and lead ores together, suggesting a relatively standardized technology for both metals:

All furnaces are built of clay and brick. The base is a good 2 chi (64 cm) long, its thickness is over 1 chi (32 cm), both sides gradually slant inwards, and the top is rounded. They can be 8 chi (256 cm) high, and the space inside is called a vat. There are doors in the front for adding charcoal and below is the *jinmen* (metal gate,) which is usually blocked with clay. It is opened only when the furnace is tapped. There is a hole near the bottom that is at times closed, but at others opened in order to let out debris. There is another hole in the back wall for ventilation. The copper furnaces have another hole above the ventilation inlet, which is used to observe the fire. Silver smelting furnaces have flat bottoms, while those of copper furnaces are shaped like a wok.

The furnace was built from refractory stone and clay, with a height of about 2.5 m and a rectangular base some 0.8-0.9 m wide and deep. The thickness of the walls was over 30 cm at the base, and the sides slanted inwards. The only constructional difference between copper and lead furnaces was the hole for observing the fire in the front and the rounded shape of the chamber bottom in copper furnaces, while lead furnaces had no observation holes and flat-bottomed chambers (Figure 4).

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60 Angel and Scharizer (1932), p. 221.

61 *Diannan kuangchan tulue, juan shang*, p. 7b.
Figure 4. Drawing of a lead smelting furnace by Xu Jinsheng 徐金生, c. 1840.

SOURCE: Diannan kuangchan tulue, unpaginated illustrations.
The description of the smelting process follows:

In all newly erected furnaces, the vat is first lined solidly with a mixture of clay and salt, this is called *tanglu* ‘enamelling the furnace.’ Next, the bottom is laid out with ground burning charcoal, this is called *shaowozi* ‘burning the nest.’ About 1 to 2 double hours later, pillar charcoal is placed in upright and the bellows are worked at full power, so that the flames cover the charcoal and ore evenly, as these are constantly loaded into the furnace. Above the ventilation inlet, the ore and charcoal form a rod, which has the shape of a bridge. While the entire furnace is red, this rod alone is black and called *zuizi* ‘beak.’ To guard (*kanhou*) the fire actually means watching this rod.

Three people work the bellows, they change every double hour, which is called *huanshou* ‘changing hands.’ They have to work evenly, for, if the wind is too strong, the ‘beak’ will turn red and fall off. If it is too weak, the strength of the fire will be insufficient and the ore will not transform, but stick to the walls; this is called *shengpang* ‘producing a fat one.’ Six double hours make one shift, two shifts are called a *duishihuo* ‘matching hour fire’ a common term for “same time next day,” three *dingguaihuo* ‘not-quite four fire,’ four *liangdui shike* ‘two pair-hours,’ and six *ersihuo* ‘two-four fire’ …

When the firing in the furnace does not go well, the molten ore turns into a lump; this is called *tai heshang tou* ‘lifting the monk’s head.’ This can happen when the materials are not mixed correctly. When the metal gate suddenly breaks and the liquid ore flies out, this is called *fang paozhang* ‘setting off firecrackers,’ and injuries are inevitable, but fortunately this is rare.

In lead mines, ‘enamelling the furnace’ and ‘nest burning’ are the same, but the bellows are worked at an easy rate. Alternating tappings of slags and lead can be kept up for up to seventy to eighty shifts.
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Figure 5. Cast iron furnace worked with two wooden flap bellows depicted in Aobo tu, a work on the salines of Zhejiang in the early fourteenth century.

The firing in the standing furnaces could continue by loading from the top and tapping for slags and rich lead at regular intervals for as long as the somewhat mysterious qiaoheng 橋衡 'bridge,' could be kept in place. This structure apparently was a non-liquefied portion of the load just above the air inlet that served the controlled descent of the material into the melt. A

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Diannan kuangchan tulue, juan shang, pp. 7b-8a.
double hour is equal to two modern hours, with slight variation due to seasonal adjustments to the length of days and nights.63

Ventilation was provided by large piston bellows that were worked by three men. On account of the long shifts, it appears that in the team of three, two men worked the two handles at each end of the bellow, while the third rested. In a list of furnace implements, the standard large bellow (Figure 6) is described as a hollowed tree trunk with a diameter of 0.4-0.47 m (1.3 to 1.45 chi) and a length of 3.8-4.2 m (1.2 to 1.3 zhang) (also see Figure 7).64

Lead smelting appears to have been considerably simpler than copper smelting. It did not require monitoring and the working of the bellows was less intensive. The comparatively low temperatures required for smelting lead explain the difference. Continuous operation of the furnace could last up to 40 days.

Yamaguchi confirmed the initial firing of new furnaces that Wu Qijun called the “burning of the nest” for the Kuangshan Mines in northeastern Yunnan in 1912:

For the first heating of the furnace, a small amount of wood charcoal and haitan 骸炭 ‘bone charcoal’ is used. After half a day, a small amount of ore rock and kuanghuan 矿鍊 ‘ore coins’ is alternatingly added, then more “bone charcoal” is thrown in, so that the ore gradually smelts. After a day or two, the furnace has reached the appropriate state, and now the “bone charcoal” is exchanged for coal.

初因熱爐用少量之木炭及骸炭，經半日後交互徐投少量之礦石及礦鍊，復投以骸炭，漸令熔融礦石，迨一二日後，爐內始成適當之情態，乃換骸炭以石炭。65

‘Bone charcoal’ denotes coke. Since coal was used in the Kuangshan Mines for zinc distillation, its presence is certain, and specific applications in other processes probable. The process apparently created a heat-resistant glazing of the furnace walls that prevented the molten ore from sticking to the walls. The identification of kuanghuan 矿鍊 as ‘ore coins’ is uncertain. As a specification of the ore corresponding to kuangshi 矿石 ‘ore rocks’ it probably refers to smaller granules, reminiscent of coins in size.

63 The twelve-hour system divided each day into six daylight hours beginning at sunrise and six night-time hours beginning at sunset. As the length of day hardly varies in the subtropical parts of China, the inbuilt seasonal variation is not relevant here.

64 Diannan kuangchan tulue, vol. 2, p. 10. The entry adds that bellows built from airtight boxes were occasionally used, but produced a weaker airflow, and that small bellows worked by a single man were used for some purposes.

65 Yamaguchi (1912), p. 103.
Figure 6. Drawing of a small bellows by Xu Jinsheng 徐金生, c. 1844.

SOURCE: *Diannan kuangchan tulue*, unpaginated illustrations.
While Wu Qijun suggests a single standard type of furnace in copper and lead smelting, other Qing sources record several types of furnaces. Huang Mengju lists five in descending order of size. His account records over 1 zhang (3.2 m) in height for the largest, the ‘general’s furnace’ (jiangjun lu 將軍爐). The others were named the ‘lord’s furnace’ (laojun lu 老君爐).
老君爐, ‘moon-embracing furnace’ (huaizhong bao yue lu 懷中抱月爐), biao-furnace (biaolu 标爐) (literally ‘target’ or ‘flag post’), and ‘Bodhisattva furnace’ (guanyin lu 觀音爐). The first two types, and probably also the third, would have been tall standing furnaces, commensurate with those described in the Diannan kuangchan tulue, while the biao furnace might have been different and the name ‘Bodhisattva furnace’ suggests a squat shape. The biao-furnace appears in a later source and is discussed below.

Cupellation

The term zhao 貝 ‘hood’ is used as the standard term for cupellation hearths in sources from the eighteenth century onwards. The word unmistakably identifies a closed structure. Wu Qijun describes two types; the ‘toad hood’ (hama zhao 蛤蟆罩) and the ‘seven stars hood’ (qixing zhao 七星罩):

Small ones are called ‘toad hoods,’ for their shape resembles a toad. The lower part is a mud platform 3 to 4 chi (96-128 cm) long and over 1 chi (32 cm) across. The hearth consists of four mud walls, over 1 chi (32 cm) high, with a roof that looks like the back of a fish. In the front is an upper opening to let the fire out, and a lower opening that is never closed for watching the fire. The bottom is covered with ash and lead is placed in the middle, while the charcoal is put atop ‘sand bars’ (shatiao 沙條). After smelting for over two shifts (24 hours), the silver floats inside the hood mouth and an iron tool is used to cover the surface with water, at which point the silver consolidates into flakes. The liquid slag sinks down into the ashes; this is ‘bottom mother’ (dimu 底母). After the silver has been removed, the hearth is demolished and rebuilt.

小曰蛤蟆罩，形似之，下為土臺，長三四尺，横尺餘，四周土墙，高尺許，頂如魚背，面上有口以透火，下有口不封以看火候。鋪炭於底，置鉛其中，炭在沙條上，煉約對時許，銀浮於罩口內，用鐵器水浸蓋之，即凝成片。渣沉於底，即底母也。出銀後即坼毀另打。

66 Diannan shishi, p. 59a

67 Different Chinese characters that are all pronounced biao appear in the sources. Since the connotation is, therefore, uncertain, we use the Romanization to refer to this furnace.

68 The character for “charcoal” (tan 炭) is a misprint of “ash” (hui 灰). Ash appears as the hearth lining below and the same phrase and reoccurs in the description of the ‘seven stars hood.’

69 Diannan kuangchan tulue, juan shang, p. 11a
The ‘toad hood’ was a small, oblong structure with a rectangular base and domed roof. If the measurement “across” between 32 cm and 64 cm in fact refers to the outside width of the structure, the hearth would be the shape of a groove. If it refers to the front only and if the furnace was toad-like, as the name implies, the structure and the chamber inside may have been oval in shape.

The front had two openings, one serving as a vent and the other for watching the fire. The hearth had the shape of a small trough that slanted towards the front, so that the silver would collect “inside the hood’s mouth.” Inside this chamber, the lead was separated from the charcoal in the upper part by the ‘sand bars.’ The text makes no mention of ventilation. It appears that the process continued by the draft effected by the two openings until all the lead had been oxidized and absorbed into the ash, a process lasting over 24 hours. The hearth was then dismantled and rebuilt.

‘Seven stars hoods’ were considerably larger:

The large ones are called ‘seven stars hoods.’ They are shaped like a grave mound and, therefore, are also called ‘grave-door hoods’ (mumen zhao 墓門罩). The base is, similarly, a mud platform, 6-7 chi (1.92-2.24 m) in length and 2 chi (64 cm) across, and [the hearth] is formed by four mud walls with a round roof that has seven holes in it to let the fire through—hence its name. The front is 2 chi high, with an upper opening for adding charcoal and a lower one called the ‘metal gate’ that is sealed with mud boards; these are gradually killed [= broken down]. The hearth bottom is covered with ashes, the ore is mixed with lead and placed upon these. The charcoal is placed on top of the ‘sand bars.’ After about two double hours (2-4 hours), the metal gate is opened, the solid slags are driven off once with an iron hook,70 and the gate is closed again. After 1 to 2 double hours (24 to 48 hours), the silver similarly appears inside the mouth of the hood. After the silver is tapped, more ore and lead are added. Letting out silver and adding ore allows the process to continue for over a month, until [the hearth] cracks and has to be rebuilt. For this reason, these hoods are also called wannian zhao 萬年罩 ‘eternal hoods.’

大曰七星罩，形如墓，又曰墓門罩，下亦土台，長五六尺，幅二尺，四周土墙，頂圓，有七空以透火，因曰七星罩。前高二尺，上口添炭，下口為金門，土板封之，後依次而杀。鋪灰于底，置礦於上，掺於鉛，炭在沙條之上。

70 The implement is described as an iron rod that was 2.6-2.9 m (8-9 chi) long with a wooden handle of 32 cm (1 chi) of which the tip of about 32 cm was bent. See Diannan kuangchan tulue, vol. 1, p. 10a
The illustrations on the first pages of Wu’s work show a ‘seven stars hood’ (Figure 8).

The name of the hood originated from the fact that the fire shone through the seven holes in the roof, which resembled the seven brightest stars in the Plough constellation.

The measurements of length and width present the same incongruity as that of the ‘toad hood.’ They are also not in agreement with the dimensions shown in the drawing. The recorded length of “5-6 chi,” with a width of only “2 chi” would imply an extremely narrow chamber, especially if the walls were 30 cm thick. As the length is given as a range between two values, the single value for the width may be a misprint, where one character was omitted. The probable reading, therefore, is “2-3 chi,” or 64-96 cm. Dimensions in this range would come reasonably close to those suggested by the drawing. Moreover, it appears that the width measurement refers to the front of the furnace only, without taking the overall oval shape into account. An oval shape is not contradicted by the illustration because the flat front and tapered shape in the depiction might be due to the illustrator’s difficulties with perspective.

The description of cupellation is summary in this as in the preceding section on the ‘toad hood,’ yet allows the identification of several differences. First, in the cupellation in the ‘seven-star hood,’ cao 肖 slags are raked off the surface of the lead bath early in the process. The sources use two terms for slags: zha 直, which is also the modern term, apparently refers to common, liquid slags; while cao 肖, which denotes more solid substances, including dross and speiss.72 The specific use of cao probably indicates a pasty consistency of the impurities that collected on the surface of the lead bath. The fact that this waste product is mentioned for the ‘seven stars hood,’ but not the ‘toad hood,’ may have to do with the large size and the presumably far larger load. The second difference is the duration of the process, with up to two days for the ‘seven stars hood,’ in comparison to one day for the ‘toad hood.’ The difference in duration corresponds to that in dimensions. Third, the silver was tapped or ladled out at the end of the cupellation in the ‘seven stars hood,’ suggesting an interruption of the process before all the lead had been absorbed or tapped. Fourth, the apparently continuous operation of the ‘seven stars hood,’ while the ‘toad

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71 Diannan kuangchan tulue, juan xia, p. 11.
72 This interpretation is based on the terminology in Wu Qijun’s Diannan kuangchan tulue and Song (1902).
Figure 8. Drawing of a ‘seven stars hood’ by Xu Jinsheng 徐金生, c. 1844.

SOURCE: Diannan kuangchan tulue, unpaginated illustrations (numbered labels and English translation by authors).
hood’ was dismantled after a single process. The description suggests that a new load of lead bullion was added immediately following the removal of silver. If this was in fact the case, it raises the question of what happened to the litharge, as the text mentions no tapping, nor its absorption by the ash lining. Since the ash lining could have only absorbed a finite amount of lead, uninterrupted operation appears impossible.

Wu Qijun’s compendium contains a number of excerpts from reports by local officials that date to the second half of the eighteenth century. Two of these mention large standing furnaces for lead smelting and cupellation hearths in the context of treatments of copper-silver ores. The report on the Baiyang Mines, which exploited copper-silver ores, contains the following additional information:

The yinzhi 銀汁 ‘silver juice’ is put into cupellation hearths. These have the shape of upturned sound bowls and measure about 3 chi (96 cm) high, 2 chi (64 cm) wide and over 1 cun (3.2 cm)73 deep. Each hearth is loaded with 50-60 jin (30-36 kg) of liquid silver and produce ingots of mine silver weighing 1-2 liang (37-74 g).

‘Silver juice’ refers to lead bullion, whilst ‘mine silver’ (changyin 銀) refers to crude silver that had to undergo refining to reach the standard of monetary silver.

The report documents small closed structures with domed roofs similar to the ‘toad hood.’ The measurements remain somewhat unclear, due to a writing error in the numbers or the depth. The load being below 36 kg, however, implies quite a small structure.

Huang Mengju specifically describes the direct cupellation of ‘frying ores’ (zha tong 炸硐) in small cupellation furnaces:

Frying ore ... need not be smelted, but it is too rare to fill a furnace. Therefore, they build hoods from yellow mud, with sieved ash for the bottom. First, other lead is placed on the ash, then the charcoal in the hood is lit to melt the lead, and the ground-frying ore is sprinkled into the liquid lead, like vegetables cooking in water. Thus, the desired metal enters the lead, then then lead is absorbed into the ash, and the silver reveals itself. This is the method for frying ore.

73 A misprint, possibly of yi — (one) instead of shi — (10) or shi — (11). 10 cun converts to 32 cm, 11 cun to 35 cm.
74 Diannan kuangchan tulue, juan shang, p. 43a, quoting from the survey recorded in Wang Chang’s eighteenth century work.
According to this source, very rich ores were sorted and stored until the amount was sufficient for cupellation. Small furnaces were built to fit the available amount of ore. Huang Mengju notes that the ash for the lining was sieved, indicating especially careful preparation. After the lead was brought to melting point, the ore, which was crushed to small granules, was sprinkled in. It appears that the process continued until all lead was absorbed in the ash lining and the silver remained.

In the following section on the cupellation of “great fire ores,” Huang provides more detail on the process and its products:

The lead is then loaded into hoods and thoroughly smelted by fire, until it becomes juice. Matter swirling on the surface forms you-lumps, while that which enters the ash becomes ‘bottom mother.’ When the you-lumps are gone and the bottom is dry, the silver remains. The you-lumps and the ‘bottom mother’ can be re-smelted for lead. In lowering the hood, if the smelter obtains 90 liang (3.33 kg) of silver and re-smelts some 2,000 jin (1.184 t) of lead, which sell at some 20 liang, he achieves a gain of merely 10 liang. At yields of only some 60 to 70 liang (2.22-2.59 kg) of silver, he will make a loss. Hence, while mining is very demanding, smelting is not easy, and only the highly capable will avoid losing money and make a profit.

The term youtuan ([金+幼 団]) uses the different character 挝团 in Wu Qijun. Differentiated from the lead oxide slags by its frothy and lumpy appearance, it can be identified as lead oxide carrying impurities and gathering on the surface in the early stages of oxidation. Both lead products were re-smelted for metal lead at Kuangshan.

75 *Diannan shishi*, p. 61a.
77 *Diannan kuangchan tulue, juan shang*, p. 6a. The definition reads: 罩之底母曰渣，滓捲而成塊曰鉛團.
Huang’s account covers the operational chain from the smelting of between 5.9 t (10,000 jin) and 1.8 t (3,000 jin) of ore for lead bullion to the marketable products of 3.33 kg (90 liang) of silver and 1.2 t (2000 jin) of metallic lead. Although the expression “lowering the hood” is suggestive of a single cupellation operation, this can be excluded on account of the large amount of produced lead. Because the loss of lead due to volatilization in both cupellation and re-smelting and the imperfect recovery in reduction-smelting, the amount of lead bullion that entered cupellation would be considerably higher than the recuperated 1.2 tons. If we assume an amount of at least 1.5 tons, short of re-charging, this load could not be treated in the known cupellation furnaces. It appears that the gist of Huang’s account is that 5.9 tons of ore commonly yielded only 3.33 kg of silver and 1.2 tons of metallic lead. This would indicate an extractable silver content of 562 g/t in the dressed ore, correlating with the economic minimum of 1 petzi.

The sources dating from the later eighteenth century to the 1840s reflect different treatments for silverized galena and for rich silver ores. The scale of operations appears much increased compared to the Song and Ming records. The direct cupellation of rich silver ores is not recorded in the earlier sources. It appears that in Qing period Yunnan rich ores were dressed but not roasted and directly cupellated with added metal lead in small ‘toad hoods,’ while in all earlier processes the prepared and roasted ores were first smelted into rich lead and subsequently cupellated.

Terminological continuity suggests a line of tradition in cupellation technology from the ‘toad furnace’ in Song Yingxing and specified as in use in Chuxiong, and the ‘toad hood’ recorded from the second half of the eighteenth century. If this was the case, the ‘toad furnace’ of the late Ming was a closed structure, rendering the illustration in Tiangong kaiwu useless. The notes added in the reprint of Song Yingxing’s account in Diannan kuangchan tulue state that Song’s cupellation process was a “former smelting method, now [replaced by] a more advanced and simpler one” and that the toad furnace of Chuxiong was the “method of the present-day hood” (jin zhao fa).78

Crucial aspects of the technology, specifically the question of ventilation and the ‘sand bars’ as the structure that separated the lead bath in the furnace chamber bottom from the charcoal in the upper part of the chamber cannot be explained on the basis of the materials investigated so far. These questions are pursued further in records on late traditional technologies.

78 Diannan kuangchan tulue, juan 1, p. 25. The text states: “former smelting method, now superior and simpler” qian lianfa, jin geng jingjian.
Traditional technologies, 1870-present

Materials on traditional technologies reflect practices that continued after the period of highly intensive exploitation up to 1850. These however, were not unchanged but adapted to economic and technological conditions than underwent great transformations. The loss of populations across the Southwest, the destruction of the main markets for mining products in eastern China, and the destruction of capital reduced mining to a village industry in many formerly important sites in the late nineteenth century. Technologies hence can be expected to have been adapted for simplicity and for the re-exploitation of historic waste materials. Subsequently, while the Southwest mostly remained an impoverished hinterland, the industrial transformation made itself felt in changing transport arteries to railway lines and motor roads, with industrial smelting established at some sites, while local and individual enterprises often used traditional technologies with minor modifications, as these were available and required little capital. This section re-explores the sequence of treatments that has been found in Qing sources for additional information relevant to understanding historical technologies.

Ore dressing

In the 1990s, He Xiaoli of Fulongchang 福隆厂 (the village on the site of the former Fulong Mines) reconstructed historical ore dressing from remains that he found on the gangue dumps and in workings of the Fulong mines, which had been exploited from about 1800 to 1850. The modern village is located at 3200 m above the Lancang 澜沧 river in the upper reaches of the Mekong river basin. According to local tradition, it was largely deserted following the slaughter between Han and Muslim Chinese mining communities, with some old families remaining and the majority of the present inhabitants having moved in since the late nineteenth century. Re-smelting of historic slags for lead was a longstanding village industry. When slags were becoming scarce, He Xiaoli decided to revive the exploitation of ores. He reconstructed ore dressing processes on the basis of findings. He knew of grinding and pounding stones on a slope that is covered in chips of gangue to a depth of several metres, with the remains of artificial ponds below. In addition, he discovered two types of sieves in old workings (Figure 9); both were similar in size, but one type had a coarser mesh size, while the other was finer and probably laid out with silk gauze, as He Xiaoli gathered from a piece of fabric that he also found. On the basis of these objects, he reconstructed a process in four steps, consisting of coarse crushing and washing the ore with the coarse sieves, followed by fine crushing and washing it in the fine sieves. He and his team treated
Figure 9. He Junzhong presents one of the bamboo sieves reconstructed by He Xiaoli.

SOURCE: Photograph by Yang Yuda, 2011.
lead and zinc ores in this manner, before carrying them by pack mules to Hexi 河西, then the nearest smelting plant at a distance of some 40 km.\footnote{He Xiaoli, communication during the authors' field visit 30 to 31 March 2011. He Xiaoli holds a BA degree in law and his keen observation is evident from the information that he provided as well as from his success in operating mines in his home village. As Fulongchang is very remote, he nevertheless had no access to written materials but relied on his own observations and local traditions.}

He Xiaoli’s findings and observations show that ore crushing was carried out on stone slabs and may have used stones as well as mallets and confirms that the different flotation processes used different sieves. Whether the historic process consisted of two different steps, as He assumed, or targeted different ores is impossible to establish.

Zhang Shi’an’s account of traditional technologies at the Munai 募廼 Mines in southwestern Yunnan likely dates to the 1930s. Zhang provides further detail on the sizes of ore granules, noting that most ore was finely ground, while very rich ores were broken up only to the size of maize corns.\footnote{Zhang (n.d.).} This suggests that different ores were dressed to different fineness, with very rich ores left as comparatively large granules.

**Roasting**

Roasting is documented from the Song sources discussed above, yet the first specific description of the process dates to around 1900. In a volume compiled in 1900 and printed for use at the first mining schools in Sichuan, Song Gengping elaborates on the technologies recorded by Wu Qijun. He may have used records from the mining administration of Sichuan province or relied on his own observations. Song describes roasting as a process in two steps:

As for the roasting pond, it is larger than a room, over 1 zhang (3.2 m) in width and length, and 8 to 9 chi (2.56-2.88 m) high, while its depth [relative to the surrounding ground] is 8 to 9 can (26-29 cm). The bottom [of the pond] slopes down and the walls slant inwards slightly towards the top. In addition, a groove is left for lighting the fire. Only wood is placed horizontally and vertically, [the ore] is piled up in many layers. A layer of fine charcoal is laid firmly over the top, and the charcoal has to be then covered with pieces of ore, so that it is flat, but open to the sky. The fire is lit under the [unidentified term] and eats its way up for one day and night. When the fire has burnt out, the ore is once more crushed with iron mallets and washed, so that jiahuang 夾黃 ‘yellow inclusions’ and muxiang 木香 ‘incense’ are removed. Then it is again roasted and washed to rid it of fucaozi 芙曹子 ‘hibiscus’.
The term *paotan* is an adjective-noun compound, with *pao* still in common Yunnanese use, describing a light and fine texture. The three impurities, ‘yellow inclusions,’ ‘incense,’ and ‘hibiscus’ cannot be identified, but it is likely that their yellow colour indicates sulphide compounds.

The roasting stacks had a surface of roughly 12-15 m² and a height of 2.5-3 m. The process was started with wood, which fulfilled the double function of leaving ventilation channels in the stack after being reduced to charcoal. The first roasting was interrupted after about 24 hours, the pile was taken apart, and the ore crushed and washed again to remove impurities. After the second roasting, the ore was ready for smelting.

The relatively elaborate process may have been developed for removing specific impurities. As a similar process of thorough crushing and washing was known in Europe to remove zinc oxide, Song’s roasting process may have targeted this metal, the presence of which caused problems in the smelting process.89

**Lead smelting furnaces**

Data on standing furnaces in late traditional sources mostly record larger structures than those in the *Diannan kuangchan tulue*. The most precise is a scale drawing of a furnace at the Gejiu Mines by Émile Rocher dating to 1870 (Figure 10). The Gejiu mines are an ancient exploitation with a rich archaeological record, and they became the leading silver mines during the Ming. The furnace is nearly 3 m high, with a chamber of about 30 cm in diameter.

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81 Misprint of nai 乃.
82 Misprint of chao 朝.
83 Unidentified character.
84 Written with the shi 石 radical.
85 Presumably a misprint of fu 贏.
86 Written with the shi 石 radical.
87 Zhang (n.d.).
88 Song (1902), juan 1, p 36b.
89 Schnabel (1894), p. 323.
Figure 10. Drawing of a lead-smelting furnace by Émile Rocher.

Furnace for smelting tin ore and argentiferous lead ore

SOURCE: Rocher (1879), vol. 2, figure 7 (English translation by authors).
In this period, silverized galena was still worked at Gejiu. The drawing with a reference scale shows a simple furnace ventilated by a large bellow. While Wu Qijun recorded that a supervision hole in the furnace back was no necessary for lead smelting, the Gejiu specimen did possess an opening in the back wall just above the air inlet.

Yamaguchi Yoshikatsu, who visited the Kuangshan Mines in 1912, records an even larger furnace. His sketch suggests a total height of almost 5 m, and a chamber diameter of about 0.5 m (Figure 11).

The dimensions of the furnace might be overstated. Yamaguchi observed that silver extraction still existed, but the re-exploitation of old slags may have been the main occupation by his time. In the period, the shortage of capital inhibited the development of underground mining, while changed conditions in lead trading encouraged re-exploitation. Restrictions on marketing metallic lead—still enforced in the 1840s—probably were lifted about 1850 or became ineffectual with the civil wars and were not revived during the late Qing. With silver ores no longer targeted, larger furnaces may have been more economical.

Later records concerning the same mines, which likely date to the 1930s or 1940s, record an 'elephant foot furnace' (xiangjiao lu 象腳爐). This structure was less than 2 m high and had a lower production output than that recorded by Yamaguchi. The name of the furnace implies a large diameter. The changes in the furnace shapes may reflect variants that existed previously but are not recorded in the Qing sources. Alternatively, they may have been a rationalization that aimed at extracting lead while reducing the labour input.

He Junzhong remembered furnaces for re-smelting historic slags for lead used around 1960 at Fulong Mines as 1.2 zhang (3.84 m) high, with a circumference of 8 chi (2.56 m), and a chamber 6 chi (1.92 m) in height that narrowed towards the bottom. He added that the extraction of metallic lead was not very efficient.

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90 The ban is still reported as an economic problem for the Yunnan mines in Diannan shishi, p. 58a-66b, but Lin Zexu’s reform proposals of 1848-1849 are thought to have been granted. In the event, they had no practical effect, as the mining industry collapsed in the civil wars.

91 According to data recorded by the smelting plant from 1963 to 1989, the lead content in the slags that were re-exploited from 1963 on average reached only 5%, see Yunnan Huize qianxinkuang (1992), p. 212. This unusually low content reflects earlier systematic re-exploitation for lead oxide, most probably from the eighteenth century at the latest.

92 Ibid., p. 154.

93 He Junzhong, communication on 31 March 2011.
Figure 11. Horizontal (above) and vertical (below) cross-sections of a lead-smelting furnace by Yamaguchi Yoshikatsu.

Wan Xingkui 万兴奎, an informant at the Lema 樂馬 Mines in northeastern Yunnan, also recalled a smelting furnace that was still in use in the late Republican period. The structure consisted of, “a wall, with 6 men working the bellows behind, and a furnace that looked like a stove in front.”94 Traditional stoves are built from clay with a diameter of about 1 m and a wide opening at the top for a wok to fit. The description suggests a rather wide furnace that may have been similar in shape to the ‘elephant foot furnace’ in use at the nearby Kuangshan Mines a decade or two earlier.

The increasing sizes of lead smelting furnaces that still employed traditional bellows suggest that lead smelting technologies survived and were adapted in the re-exploitation of slags.

The biao-furnace

From the pre-1850 sources, we expected that all lead-smelting furnaces were standing furnaces with some variation in sizes. The description of the biao-furnace—literally ‘spike furnace’ (biao lu 鐢爐)—by Song Gengping, however, suggests a different structure:

The ‘spike furnace’ is over 6 chi (1.92 m) high, 7 chi (2.24 m) wide in length, and 2.4 to 2.5 chi (77-80 cm) deep. Its shape is like a stack of woven basket trays with a skull cap on top, but with ladder-like steps on both sides ascending to the top. It is built from heaped bricks and stones all around, the chamber inside is wide at the top and narrow at the base, and at the bottom a pond is made. The pond is outside the ‘spike furnace’ and the furnace’s metal gate sits above this; when it is biaohua 鐢化 ‘spiked,’ the rich lead flows out into the pond. Inside, on top of the furnace roof, soaked charcoal is loaded into what is called a horse manger (the charcoal layer is over 1 chi (32 cm) thick, and the ore is placed on top of it). When the charcoal turns red, the ore transforms by itself and trickles down. From one side, charcoal is added. The ore “manger” (cao 曹) is over 4 chi (128 cm) long and over 2 chi (64 cm) wide; there is no lu qiao 煉橋 ‘furnace bridge’ inside (only one person is needed on the furnace to add ore and charcoal, and to stoke it regularly using an iron stick). The upper part is wide and narrows gradually; the bellows are mounted at the back about half

94 Wan Xingkui, communication during fieldwork by Yang and Kim, 9 April 2011.
95 Written with the shi 石 ‘stone’ radical.
96 Variant character with the ‘stone’ radical.
way up (below the furnace, one man prods\textsuperscript{97} the fire and lets out the lead, but usually the metal gate mouth is prodded evenly in order to prevent rusty lumps from forming, for then the lead can no longer flow out. It is reckoned that when the fire is kept going uninterruptedly, and if the furnace works well, 800 to 900 \textit{jin} (474-533 kg) of pure lead can be obtained per day. Because the bellow is large, it is driven by water, for continuous operation day and night only 4 people [in two shifts] are needed.

The measurements are somewhat confusing, as ‘width’ and ‘length’ are used in referring to the same dimension, while the depth is unclear. The description of the shape as a, “stack of woven basket trays with a skull cap on top,” does not help much with gaining an impression of the structure, as we are no longer familiar with the objects and cannot identify the shape of the basket trays. However, the shape of the trough with a length of over 128 cm and a width of over 64 cm is clear, indicating a furnace of considerable depth and an oblong shape. The loading from the top and the absence of the ‘furnace bridge’ are evidence of a technological difference. Continuous operation appears to have been the rule. As Song Gengping systematically uses the term \textit{lian} 銻 for rich lead and \textit{qian} 銅 for lead, the use of the binom \textit{lianqian} 銻銅 for product probably indicates that the furnace was used to smelt both silverized lead and metallic lead.

The accompanying sketch employs a perspective that mixes the frontal view with interior structures depicted from above (Figure 12).

\textsuperscript{97} The term \textit{bo} 拨 appears here in relation to tending the fire (\textit{bohuo} 拨火) and preventing the metal outlet from becoming blocked (\textit{boyun} 拨匀), so it appears to indicate a back-and-forth or circular movement with a rod.

\textsuperscript{98} Written with the ‘stone’ radical.

\textsuperscript{99} Variant character with the ‘stone’ radical.

\textsuperscript{100} Song (1902), \textit{juan} 1, p. 35b-36a.
Figure 12. Drawing of a ‘horse-trough spike furnace’ from Kuangxue xinyao xinbian.

The drawing shows the furnace’s steps, the three internal stories, the water wheel, the crank that moved the bellow piston, and the iron rod for prodding the melt sticking out from the top, which may have given the furnace its name.

While the process remains partly unclear, the furnace evidently was labour-efficient, needing only two operators, or four men in two shifts for continuous operation. It thus represents a different technology from the standing furnace described by Wu Qijun. The mention of a biao-furnace in Huang Mengju reflects that it was in use in northeastern Yunnan in the 1840s. As this furnace is not otherwise recorded and appears to have played no role in the smelting by traditional methods in the late 1950s, it may have been a technology confined to northeastern Yunnan and western Sichuan.
Cupellation furnaces

Records dating between 1870 and the 1950s document cupellation furnaces that were simply called ‘hoods’ (zhaozi 罩子) and were almost rounded in shape. Émile Rocher carefully recorded silver separation as he observed it at the Gejiu Mines in 1870, using observations of ongoing smelting operations and information provided by mining entrepreneurs and smelting masters:

The hearth, which resembles a baker’s oven, is built from bricks that are covered in several layers of refractory sand.

Figure 8 shows the cross section and front. The diameter is 1.5-3 m, and the height about 1.75 m. The bottom is slightly concave and formed from several layers of lining and it inclines towards the loading opening, which eases cleaning the hearth after the operation. The upper opening is for loading fuel, which is hardwood charcoal in bundles of 4-5 jin (4-5 kg). The bundles are introduced crosswise and positioned as lightly as possible to prevent damaging the grid of sand bars on which they rest. The dome has a height of about 1 m. In its centre, between the dome and the bottom, a semi-concentric grid is placed. It is made of heat resistant sand and supports the fuel. The fire is lit and, as soon as the hearth has heated up, the lead is placed in the bottom, where it soon melts.

The opening used for loading is then blocked with sand up to the height that the bath will probably reach.

As the temperature rises, the metal oxidises and soon litharge (PbO) forms. Once it begins to appear, more charcoal bundles are added and the whole grid is filled. The temperature continues to rise, and oxidation is rapid. When the entire bath is covered in litharge, the worker cuts a groove with his hook, which he deepens as the level of material falls. When the process has reached this point, all that remains to be done is supervise it, make the litharge flow, and keep the temperature stable and high to ensure that all the lead transforms into litharge.

The hearth is called ‘hood’ (zhaozi 罩子). A load is 700 jin (420 kg). The cupellation process is very slow; it

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101 The character of the same pronunciation is misattributed, either by Rocher or by his informants.

102 The weight of 420 kg is standard for 1 jin to 0.6 kg. Rocher, however, recorded elsewhere that a “furnace jin” was in use in the smelting industry that weighed approximately 1 kg.
takes three days for the material to transform to litharge, which is of excellent quality.

The end of the operation is involves lowering the temperature. At the point when all lead is oxidized, it gives an intense light; the remaining material appears to burst into flames. At this moment, the treatment is considered finished. The temperature is lowered and water is thrown in to ease cleansing. The silver that is left at the bottom is far from pure, it still contains 15-20% of impurities and needs refining to reach the 98% standard.

After each operation, the loading opening is enlarged to allow a man to enter the hearth for repairs. The lining in the bottom usually contains much litharge and some silver, therefore it is broken up and replaced by new layers.\textsuperscript{103}

Rocher’s drawing of the furnace with a scale is shown in Figure 13. Unlike the oblong shape of the earlier recorded hoods, this hearth is almost round. Rocher precisely describes a reverberatory hearth in which the fuel is loaded in the top half of the chamber and separated from the lead melt by a grid made of refractory sand and clay. The text provides no specific information on the grid and makes no mention of ventilation. Most of the oxidized lead appears to have been tapped, with only a small proportion absorbed by the bottom lining.

The load is specified as 700 jin. At the weight of 0.592 kg per standard jin, this is equal to some 415 kg. However, since Rocher elsewhere specifies that a ‘furnace catty’ of approximately 1 kg was the standard unit in the mines, an amount of about 700 kg is more probable.\textsuperscript{104} The dimensions of the hearth support this reading, Rocher’s drawing shows over 1 m diameter and a depth of up to 20 cm for the basin-shaped chamber bottom, suggesting a load that may have approached 1 ton.

Rocher’s furnace in the shape of ‘a baker’s oven’ and Wu Qijun’s ‘seven stars hood’ differ in shape and size. Moreover, while Wu Qijun seems to indicate continuous operation, Rocher unmistakeably records that a cupellation process ended with the treatment of one load. He informs us, however, that the furnace was not dismantled but restored and refitted with a new lining for the next operation. Hence Rocher’s account supports the interpretation that Wu Qijun’s continuous use referred to re-using the furnace.

\textsuperscript{103} Rocher (1879), pp. 241-243. Translation from the French original by the authors.

\textsuperscript{104} Ibid., vol. 1, p. 199.
Figure 13. Drawing of a cupellation hearth by Émile Rocher.

Fournou à coupeller employé par les industriels
du Yün-nan.

Cupellation hearth in use in Yunnan

1. bottom of hearth where the lead for cupellation is placed
2. interior of furnace
3. grid on top of which bundles of charcoal are placed to provide the necessary energy input. The grid is made from heat resistant sand.
4. opening through which the lead is loaded
5. layer of lining and sand
6. layer of very fine lining
7. layer of heat resistant sand
8. dome built from bricks
9. body of hearth
10. opening for loading fuel

SOURCE: Rocher (1879), figure 8.
Song Gengping records a ‘lotus hood’ (lianhua zhao 蓮花罩) in some detail and includes an illustration for this hearth only, suggesting that it was the most widespread type:

The lotus hood resembles the Bodhisattva hood. It also resembles the dwarf furnace used abroad, but is cheaper and more labour-efficient. Inside, it contains three stories. There is an opening in the top which is the tianshi men 天師門 ‘door of the heavenly masters,’ through which the charcoal is entered, in the middle story the rich lead is loaded and smelted into the ash pond. The hearth produces silver, while the rich lead becomes the ‘hunchbacked monk.’ The silver rests on the ash pond, while below this is the gou dongzi 狗窩子 ‘dog kennel’ that in the case of leakage, [prevents?] the ash receiving a shock. The foundation is 1.4 cun (49 cm) high and there is an opening above the pond surface to watch the fire.

The ‘Bodhisattva hood’ and the ‘dwarf furnace’ (wozi lu 倭子爐) found abroad could not be identified. The author may have had knowledge of the domed European cupellation furnaces or of modernized furnaces in use in Japan. The purpose of the ‘dog kennel’ is uncertain, as misprinted characters and cryptic formulation permits no clear interpretation. It may have provided ventilation in the furnace foundation, preventing a cracking of the foundation due to escaping humidity or providing an outlet for the molten lead in case of leakage.

The description breaks off at this point, but the text returns to cupellation hearths a few sections later:

The hood has a height of over 4 chi (128 cm), and a width of 3 chi (96 cm); the pond should be round, with a width of 2.5 to 2.6 chi (82 cm).

罩高四尺餘, 寬三尺, 池宜圓, 寬二尺五六寸。107

105 Song (1902), juan 1, p. 34a-b.
106 The possible interpretation of a channel to permit humidity escaping without damaging the structure is based on the existence of this feature in the early modern cupellation furnaces of Central Europe, which were similar in dimension to the large hoods.
107 Ibid., p. 35b.
If we assume that the measurements refer to the ‘lotus hood,’ the structure was largely identical to the cupellation hearth in use in southern Yunnan, which Rocher recorded in 1870.

In again a different section, Song Gengping provides detail on the ash lining:

The method of char burning is to use the pure ash of sweet oak branches (no other wood can be substituted), which is sieved and pounded into fine threads, and these are rolled into charcoal balls. Then, the balls are roasted in sweet oak ash, and following this forging they are ground finely again, and sieved with horse-tail sieves (this ash is prepared for the ash pond). The pond is made from loam, half dry and half wet, then the oak charcoal is put down, exceedingly finely and smoothly, layer by layer, and lightly pounded with an iron hammer, to a lining of about 4 to 5 cm (13-15 cm).

Finally, he notes that the ‘dragon spine’ (longji 龍脊) and the ‘sand bars’ were made from a special clay called huangcini 黃磁泥 ‘yellow lodestone clay,’ of which some 400 to 500 jin (240-300 kg) were required, and which were brought in from considerable distance.

The drawing of the hearth again employs a mixed perspective (Figure 14), with a frontal view on the domed hearth and the opening for loading charcoal, while the grid consisting of the ‘dragon spine’ and the ‘sand bars’ with half of the “ash pond” are shown from above, and the hearth, and the foundation with the ‘dog kennel’ in an unclear perspective.

The dimensions, constructional parts and operation identify Song Gengping’s ‘lotus hood’ as similar to Rocher’s furnace, with Song providing additional detail. The base was a solid structure, the ceramic grid consisted of a main arc, the ‘dragon spine,’ on which thinner ‘sand bars’ were placed to form a convex grid over the hearth, and that special clay was required for the ceramic grid and specially-prepared oak ash for the lining.

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108 Song (1902), juan 1, p. 35a-b.

109 之有龍骨和紗條，係遠運至，自代黃磁泥（土字旁）二騾（計重四五百斤之甫，此泥（土字旁）準備龍骨沙條用）。Ibid., p. 35a-b.
Figure 14. Drawing of a ‘lotus hood’ from *Kuangxue xinyao xinbian*.

1a. This furnace is called lotus hood, similar to the Guanyin hood.
1b. It is similar to the dwarf hood abroad, but cheaper and requiring less labour.
2a. [2 unintelligible characters] are above.
2b. This is the heavenly messenger gate.
3. [2 unintelligible characters] coal and ore are loaded here.
4. On both sides is the gate-structure of sand bars.
5. In the middle is the dragon spine, made from clay.
6. Ash pond
7. The metal gate is inside.
8. Here is the dog’s kennel to prevent leakages.

SOURCE: Song (1902), figure 14 (numbered labels and English translation by authors).
Yamaguchi records cupellation loads of 800 jin (480 or 800 kg) for the Kuangshan mines and details that the process took 31 hours for the lead to begin to convert, and was completed after 34 hours. The loads as well as the duration of the process is similar to Rocher’s.\footnote{Yamaguchi (1912), p. 107.}

Yamaguchi provides further detail for the hearth’s preparation, including the ash lining, and the placing of the ‘sand bars’:

First, 4 dou (40 l) of chestnut charcoal ash are shaped into an oval basin in the furnace bottom, exactly as in the hearth of the English-style silver separation. In order to let off humidity, an air channel is left. Then this is surrounded by tamped earth, the surface of which is covered by ash. The furnace bottom is filled with half-dry grass, on top of which the half-moon-shaped rich lead is stacked. After this, down the middle from the front to the rear, a beam of clay (the “dragon spine”) is built up, with the place of the “dragon spine” between the rich lead and the clay beam. In preparation, short pieces of charcoal are arranged in a straight line to support the dragon’s back. Once the “dragon spine” is in place, ‘sand bars’ (fired clay poles) are stuck to it on both sides, surrounding it in an oval shape and raised in the centre, exactly like a tortoise shell. But the outer rim (the perimeter) is preserved with ‘sand bars,’ which are covered with sherds of old furnace roofs and new tamped earth. When the ‘sand bars’ are in place, they are covered with sherds from old furnace roofs in several layers. After this, wood charcoal is gradually loaded onto on the “dragon’s back” and the ‘sand bars.’ When the covering is finished, the lowest end of the “dragon’s back” in front of the furnace is removed, and a working opening constructed from clay. The cover is plastered in thin layers of tamped earth, and, finally, an opening for adding charcoal is made just under the furnace roof, which narrows towards the top and faces towards the front of the furnace.

先以栗炭灰四斗，筑爐底為椭圓形，恰如英式分銀爐底，
因欲放散濕氣，留一氣縫。次以粘土層覆其周圍，表面裝
飾以栗灰，爐底之上布半枯草，草之上塗積半圓徑之粗
鉛，然後於其前後方向中央置粘土梁（現脊），粗鉛及粘
土梁之間應龍脊之位置，豫列短小之木炭，成一直線以支
持龍脊。龍脊安置既畢，輔之以砂條（燒粘土之杆），俾
成椭圓形外圍，中央隆起之状，恰如龜甲。然以豬脊（外
面）上保持砂條用舊爐蓋之斷片與新粘土塊，砂條安置
畢，以舊爐蓋之斷片以爲覆蓋，隨覆蓋之堆積，散次裝載
木炭於龍脊上及砂條上。覆蓋既成，乃以爐前除去龍脊之

\footnote{Yamaguchi (1912), p. 107.}
The accompanying sketch shows the arrangement of the bars (Figure 15).

The alternating use of “dragon spine” (longji 龍脊) and “dragon’s back” (longbei 龍背) in the text is almost certainly caused by a typesetting error.

Yamaguchi confirms the use of wood ash for the hearth lining. The installation of the convex grid is described as an intricate process, which apparently used pre-fabricated clay bars that were fused together in the firing process.

He Junzhong of Fulongchang recalled the dragon spines of historic hearths that he saw in his youth:

The lower part of the furnaces resembled a wok, about 30 cm deep, … From halfway up the wok, the “dragon bone” (longgu 龍骨) was placed. The “dragon bones” were made of sand and stone. They were placed in rows, and the charcoal came on top. From the “dragon bone” to the furnace roof the height was about 70 cm.

He Junzhong provides the additional specification that the “dragon spine” was anchored in the back and the front of the hearth, and that the hearth below was about 30 cm deep and the space above the grid about 70 cm.

In 2011, the authors of this paper found several almost undamaged remains of hearths at the Shiyang 石羊 Mines (Figure 16), and a couple of less complete ones at Laochang (laochang 老廠, literally “old mine”) site in Gengma 耿马 county. They were domed and slightly oblong in shape, approximately 1.5-2 m deep and 1.4 m wide. The roofs had between four to six ventilation holes, with the precise number impossible to establish. Two hearths also exhibited a large hole in the lower part of the back wall. The height of the original structures was uncertain, due to the erosion of the surrounding slope. The front parts stood around 1 m to 1.5 m high. They were built in rows, possibly with a wall at their backs, or on a continuous base.

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112 Interview with He Junzhong, during fieldwork by Yang and Kim, 31 March 2011.
Figure 15. Drawing of the ‘sand bars’ by Yamaguchi Yoshikatsu.

Caption: The base of the silver separation hearth
Scale 1:20
Shown is the shape of the dragon spine and the sand bars without the hood that covers them.

The remains may date to the period before the mid-nineteenth century civil wars. The Shiyang Mines are located in central Yunnan, in a very broken area divided by many deep valleys forming the upper reaches of the Yuan River. The mines were productive and worked by reportedly 10,000 men at the time, until tensions between mining communities led to an ethnic conflict between Han and Muslim Chinese, with large-scale fighting erupting in 1850 at the site. The mines are thought to have been deserted until the 1950s, with the village resettled only in the 1980s. While the re-exploitation for lead is therefore possible, silver extraction most probably ceased with the mid-nineteenth century civil wars. We found a few hearths at the Old Shiyang Mines (shiyang laochang 石羊老廠) on a ridge west of the Shiyang river, and numerous remains at the New Shiyang Mines (shiyang xinchang 石羊新廠) on the opposite ridge to the east. At this site, a few gravestones and the remains of a temple attest to small-scale exploitation in the 1860s to 1880s.

Several mines in Gengma county receive fleeting mention in the Qing records. The site near present-day Laochang village might be the Shiniu 石牛 or the Xiyi 西宜 Mines, the former recorded in the 1760s and the latter important approximately from the 1770s to about 1800. The end of exploitations is uncertain, but the recent date of re-exploitation, beginning only in the 1990s, practically excludes a dating of the cupellation furnace remains to after 1850.114

At almost all of the twenty-something historic silver mining sites visited by the authors, in addition to hearth remains, partly glazed ‘sand bars’ were found to be abundant. These were approximately 3 cm in diameter

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113 This river is more commonly known as the Red River (Honghe 紅河, or Sông cái), particularly in Vietnam.
and reached 20 cm in length. They were well-known to local inhabitants as indicators of old smelters, but their function was not known to most informants consulted by the authors.  

Records describe a similar technology used across Yunnan and western Sichuan. They agree in the oval shape of the furnace as well as the clay grid. Furnace loads were some 0.5 tons by standard conversion of the jin, and may have been 0.7 to 0.8 tons. There is no indication of the use of bellows, and the oxidation process appears to have been slow, with most of the lead oxide tapped. It ended with the removal of the silver.

Despite the narrow fronts recorded for the ‘seven stars hood’ in Wu Qijun, we identify this furnace with the oval domed hoods found in remains and descriptions. The grounds are the presence of the ceramic grid and the otherwise similar technology as well as the wide distribution of the latter, which suggests longstanding use. We conclude that the ‘seven stars hood,’ the ‘lotus hood,’ and the ‘toad hood’ were variants differing in size and in name but based on similar technology. The increase in size that is firmly documented with the ‘seven star hood’ probably dates to the mid-eighteenth century, but may have appeared earlier. As an enlarged version of the ‘toad hood,’ it can be placed in the context of the exploitation of silverized galena.

The continuous operation of the ‘seven star hoods’ recorded in Wu Qijun is questionable. The account might describe a special application that appeared commendable as particularly efficient to the author, or simply be due to vagueness in the description. Early modern European technology suggests extended operation that included re-loading under specific circumstances. In his discussion of traditional silver separation, Carl Schnabel states that continuous operation was possible in the English furnace, but required lead bullion that contain only minimal impurities, and produced silver with a relatively high lead content. In view of European technologies, re-loading may have been practiced in hoods, when galena ores with low silver content but of high purity were worked. The involvement of Xu Jinsheng in the compilation of the work could suggest that the ‘eternal hood’ in Wu Qijun recorded special conditions at Kuangshan.

The reconstruction of the technology relied on crucial aspects in late traditional records. These allowed an understanding of the grid and the reverberatory characteristics of the hearth, as well as of the ash lining. At the same time, the question of ventilation remains unsolved. Wu Qijun records a single hole for the ‘toad hood’ and seven, or more than five, for the ‘seven stars hood.’ None of the later sources mention holes in the

115 Fieldwork by the authors, 2011-2018.
hearth roof, but fieldwork finds indicate that these existed. As oxidation required a significant draught, we conclude that all hoods had ventilation holes. Moreover, no text mentions bellows in the context of silver separation. Without further evidence, we cannot establish whether the process relied only on the draught from the frontal opening to the holes in the roof, or whether the oxygen flow was supported by ventilation. The omission of specific mention in the historical descriptions might be due to the fact that bellows had already been recorded in the section on furnaces, and that these used the largest type. The fact that the temperature in the hearth was high and adjustable suggests ventilation.

Direct cupellation

While all sources of the Song to Ming period suggest that silver ores were first smelted for rich lead, Wu Qijun and Huang Mengju record direct cupellation for the richest ores, which, yielded between 2% and 50% silver. Two informants visited by the authors in 2011 confirmed direct cupellation. He Junzhong remembered silver extraction as a process in which lead and rich ores were cupellated:

Some 1000 kg of lead were placed in the bottom of the wok [the hearth], and the powdered ore was put on top of the lead. … the temperature reached up to 1200°. … in the upper part [of the hearth] over 300 jin (150 or 180 kg) of charcoal were placed. When the temperature was up, the ore was loaded. First one tray or two trays; about 20 minutes later they were fried up. One hearth was kept frying for one day and one night, 24 hours, frying 30-40 jin (18-24 kg) of ore per hour, that would be 700-800 jin (420-480 kg) in 24 hours. There were openings in the hearth, square and about 6 cun (19.2 cm) across, the upper for adding charcoal, the lower for adding ore.

Ash of the sawtooth oak was also added with an iron spade from the lower opening; it was sprinkled on the metal surface, so that the silver would not stick to the ash but would eventually come together. After 24 hours of smelting, they would get 3.6 to 3.7 jin (2.15-2.2 kg) of silver; at the very most 5 jin (3 kg).
麻栎灰从下面用铁铲放进去，洒到金属表面，银子不沾
灰，最后收到一起。罩 24 小时，银子为三斤六七两到四
斤多，没有超过 5 斤的。117

The focus on the silver ore suggests that the amount of silver in the lead
was irrelevant. The grade of the ores that He Junzhong knew or had heard
was not negligible. The 420 to 480 kg of silver ore yielded 2.15 to 2.2 kg, or
5000 g/t.

He Junzhong had collected samples from historical gangue heaps, and
sent them to the Third Geology Brigade of the Mining Department of
Yunnan Province (Yunnan sheng diikuangju dizhi san da dui 云南省地质
省地质三大队) for analysis. Results showed a silver content between 12 and
300 g/t in 21 samples, with one exception returning 3,869 g/t. The latter
sample testifies to the presence of rich silver ores that were exploited in the
past.118

Zhang Fuchang 张富昌, an informant consulted at the Shiyang Mines,
also recalled direct cupellation. Showing the authors a dark, shiny piece of
ore, he explained:

This kind of ore had to be ground into powder, then it
could be smelted directly for silver. A lead cake was
placed into the bottom of the furnace, and the bottom is
what we now call furnace-bottom-rock. The bottom of the
furnace was lined with ash and on top of the furnace-
bottom-rock was the lead cake, and on top of that the silver
[ore]. When the furnace was build, salt had to be
mixed with ash and mud to line the inside. The lower
part of a furnace had the shape of a wok, and that is
where the lead cake was placed. There was a ventilation
hole at the base of the furnace. There were two openings
in the front—one each for loading charcoal and ore. The
loading openings were about 10 cm across. The lead was
put in the ash. Ore and charcoal would be added quite
slowly. Near the loading openings, the brick and stone
carved were only 3-4 cun (9.6-12.8 cm) thick.

用这种矿石熬成粉面炼，可以直接分解成银。在炉子下面
要用铅巴来炼。在炉底下面的，我们现在就叫炉底石。炉
底下面有炉灰，炉底石上面是铅巴，铅巴上面才是银子。
炉罩子，要用盐巴拌灰泥涂在里面，罩子下面就是炉，装
铅巴。炉底下面有风口，正面要开两个口。分别装炭和

117 Interview with He Junzhong, 31 March 2011.
118 Ibid. and photographs by Yang Yuda. The results for the other samples were:
9 samples > 100 g/t; 3 samples > 300 g/t.
Zhang Fuchang’s description was based on local oral traditions. The two oral accounts are evidence of direct silver separation at the two sites in the Republican period (1912-1949). The presence of this technology confirms that the mines worked rich silver ores alongside galena ores.

Innovation and simplification

The investigation presented above has shown the utility of studying late traditional technologies to understand historical processes of the period before the mid-nineteenth century civil wars. However, a continuity in traditional technologies also involves adaptations and transformations. Some identifiable technological shifts appear to have been simplifications of the smelting process that may have occurred in response to the labour shortage after the civil wars, or even earlier to the frontier situation of rich deposits but great difficulties in finding skilled labour. Zhang Shi’an records such simplifications for the Munai Mines:

The ‘lazy furnaces’: The smelters initially used furnaces ventilated by bellows for smelting lead slags. They hired people to work the bellows. Once, there was a great rainstorm, and the workers ran away to shelter from the rain. When the sun came out and they came out again, they saw the lead still flowing out. As a result, they decided that lead smelting without bellows would work just as well. The smelters then developed the ‘lazy furnaces,’ which are still in use. Actually, the earlier furnaces, in addition to the four metal gates on each side, had four ‘fire eyes’ (huoyan 火眼) in their walls for controlling the temperature. The furnaces now have lost these holes, becoming even simpler. But smelting in lazy furnaces cannot extract all the lead from the lead slags. That is why the lead content of the ash slags of ‘lazy furnaces’ is still over 30% and they can be smelted again.

Interview with Zhang Fuchang at the Shiyang Mines, during fieldwork by Yang and Kim, 7 April 2011. Zhang Fuchang, 64 years old in 2011, is from Liangzi Tian 梁子田 Village near Dashuigou 大水沟. He displayed considerable knowledge of local history and told us that the name Dashuigou (literally big water channel) is derived from a channel built by the miners to direct water to the area.
外，還在爐壁上設有四个火眼，作用是在調整爐中溫度，現也不用這四个火眼，更是簡單。但是懶爐煉鉛，鉛渣內所含鉛質不能提盡，因此現在懶爐煉鉛棄置堆存的灰渣中還含有30%以上的鉛質，還可再煉煉。120

The ‘lazy furnace’ is described as a round cone, built of limestone, with a mixture of clay, slags and salt used as mortar. The total height was some 2-2.5 m, the diameter of the chamber 0.9-1 m at the top and 1.2-1.3 m at the bottom. The walls were about 0.6 m thick. Ventilation was achieved by four large openings in the furnace bottom, each 20x80 cm. The furnace exclusively re-smelted slags and reached outputs of about 1 ton per day, but the more than 40% of the lead in the slags could be recovered.121

The adaptations at Munai constituted rationalizations that were useful for reducing production costs and sensible as the smelters re-exploited slag dumps of half a million tons and an average slag content of 47%.122

Comparable trends can be shown by comparing the records on the Kuangshan mines, are attested in the records of Huang Mengju in the 1840s, and Yamaguchi around 1910 and again in the 1950s.

Huang Mengju’s account of the 1840s records considerably richer ores that Yamaguchi in 1912, whereas the largest furnaces recorded by Huang were still a third smaller than in Yamaguchi. The shift from the exploitation of ores to the re-exploitation of slags involved some adaptation in the furnaces. In this process, it also appears that capital and labour shortage led to a simplification of the processes, especially when slag resources were abundant.

While documentation for the latest period provides more details, extreme caution is necessary when extrapolating to the pre-civil-war period, since technical differences may have been an adaptation that responded to the needs of local villagers, who applied their traditional knowledge for mere survival, without access to capital or labour.

**Discussion**

This exploration has revealed major transformations. Changes concerned technological innovation, the geographical shift, and its concomitant conditions of mining. For the first six centuries, technologies are often only partly visible, and interpretations have to remain tentative. The reconstruction of the period from the eighteenth century onwards achieves

121 Yunnan Lancang qiankuang (1985), p. 35.
122 For the slag dump, see Meng and Chen (1940) p. 14; for the lead content, see *ibid.* and Xue (2003), p. 161.
greater detail, due to the availability of richer and more specific material, as well as because it was able to focus on the Southwest and to exploit late traditional materials.

The first period of intensive silver mining in China can be approximately dated to the tenth to thirteenth centuries, with the main mining regions in the mountain belt along the eastern coast, covering western Zhejiang, Fujian, eastern Jiangxi and northern Guangdong, and further important regions in western Jiangxi and Hunan. The written sources reflect well-developed technologies targeted on the exploitation of rich silver ores for the highland mining region in eastern China, while lead mining is not evidenced. Liu Siran’s archaeo-metallurgical study on three sites that were exploited between the eighth and the fourteenth century has demonstrated very efficient lead extraction as well as specialized technologies for the treatment of sulphides and arsenic components and for working ores with a comparatively deficient lead content. The analyzed written records reflect careful and specialized treatment and suggest that the dimensions of furnaces and hearths remained small. We therefore believe that the worked ores were relatively rich, worth the high labour input. Labour-saving innovations very approximately datable to this period are efficient bellows, such as wooden flaps and piston bellows, as well as possibly the harnessing of water power.

From the Yuan dynasty (1279-1368), silver mining shifted to the Southwest. Through the study of material remains rather than of the written records, this shift can be assessed as a period of intensive silver exploitation in this region that expanded through the Ming dynasty. In the early seventeenth century, Song Yingxing confirms the geographic shift to the Southwest and describes a set of extraction technologies that targeted lead-silver ores or combined deposits of lead and silver ores. *Tiangoing kaiwu* provides the first description of the furnace used for smelting lead bullion. The toad furnace used for cupellation can be identified as a closed structure that was probably similar to the toad hood recorded from the eighteenth century onwards. As a reverberatory furnace, it constituted an important innovation. Because cupellation in ash nests is recorded in the Song records and this technology was transmitted to Korea and Japan between the fourteenth and the early sixteenth century, the innovation can be tentatively dated to the Ming period. By realising the separation of fuel and lead bath in the same chamber, the closed structure permitted the treatment of larger amounts of lead bullion and improved fuel efficiency.

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123 Liu (2015). Among the sites studied by Liu, Baojia in eastern Jiangxi is in the eastern mountain belt, and Mengshan belongs to the region in a wider sense, while Yanshan is part of the Shanxi metallurgical region that employed a different, coal-based set of technologies.
The Ming-Qing transition, with internal wars and concomitant disasters that lasted for half a century, caused a population collapse and can be safely expected to have disrupted silver mining. With the recovery and sustained population growth from the late seventeenth century, massive intensification in mining set in. This trend is most recognisable for copper mining, due to prioritized government attention on this metal that was crucial to coinage.\textsuperscript{124} Transformations in silver metallurgy documented in detail for the 1840s show an increase in scale in smelting and cupellation furnaces. In the smelting of ores for lead bullion, the size of the furnaces increased from a height of about 1.5 m recorded by Song Yingxing to certainly over 2 m, perhaps up to 3 m by the 1840s. Moreover, the continuous operation for a maximum duration of about a month demonstrates good process control. The large and efficient bellows probably played a role in this transformation. In cupellation, a combined diversification and simplification can be recognized. Very rich ores were directly cupelled in small reverberatory toad hoods, while silver separation from bullion cakes, which were presumably obtained from silverized galena, employed very large hoods that processes loads of almost a ton in a single process. The increase in scale realized a new dimension of fuel and labour efficiency.

Some further technological changes in the period following the civil wars and through the beginnings of industrial modernization can be identified, though it is uncertain whether these were improvements in efficiency, adaptation to the re-smelting of slags, or simplifications responding to a crisis situation.

The geographic shift from eastern to southwestern China contributes to the understanding of technological change. From the Tang to the later Song period, we may assume that intensive exploitation over many centuries led to refined, often labour-intensive techniques for working poorer ores and smaller seams. By comparison, the Southwest provided massive galena deposits as well as rich ores, often in relatively accessible conditions in zones of secondary enrichment at the bottom of limestone layers. The basic conditions of known, but often not yet intensively worked deposits were favourable, presumably especially in the early period of exploitation.

These attracted Han and Muslim Chinese from many parts of China, creating a melting pot of mining traditions of eastern and northwestern China. The mix of mobile mining specialists and workers may have created dynamics conducive to innovation. Moreover, the networks of mobility and trade that developed with the industry itself, with the supply of the mines, and the marketing of their products ensured the rapid spread of new, effective technologies.

\textsuperscript{124} Vogel (1987) and Ma (2013).
At the same time, however, the distance between Southwest and the main markets in eastern and southeastern China affected the economics of mining. A journey into the mining areas from the interior of China took some two to three months under the best circumstances. For this reason, mining operations faced high costs of labour as well as of marketing. These increased with increasing distance and compounded by climatic and cultural factors, such as tropical disease as well as actual and rumoured dangers. The conditions of transport and environment placed the focus on high-value metals, such as gold, silver, cupronickel, tin and copper. In contrast, low-value metals, such as lead and zinc, were worthless, unless the deposits were located at a manageable distance from navigable waterways.

Considered against the background of the general conditions in the Southwest, we have reason to expect that the Ming period intensification took place under favourable conditions, as far as technological requirements were concerned, but faced great challenges in the fields of labour recruitment, transport, and security. By comparison, the Qing expansion took place under declining conditions at the old exploitations, while population growth and economic expansion eased the pressures of operating costs. As the economic environment presented no incentive toward lead exploitation, the overall increase in the scale of the furnaces found towards the end of the highly intensive period of exploitation during the Qing represents a gain in labour and fuel efficiency, while extraction was optimized for silver only.

The exploration of silver metallurgy from about 1200 into the twentieth century has revealed two major technological transformations. The first is the initial innovation that introduced the reverberatory furnace in cupellation and can be tentatively dated to the period of intensification of silver mining in the Southwest from the early fifteenth to the late sixteenth century. The second involves a gain in size in smelting and cupellation furnaces and can be dated to the eighteenth to early nineteenth century. The assumption of technological stagnation in late imperial China appears not to apply to silver mining.
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