The Vitriol Copper Process during the Song

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Preamble: The Wet Copper Process and Its Origins

Methods for processing copper can be broadly divided into the dry copper process and the wet copper process. The major proportion of the world's copper production today relies on the dry copper process, while the wet copper process is said to account for about ten per cent. The dry copper process involves smelting in a smelting furnace or a reverberating furnace, whereas the wet copper process is a technochemical method of copper recovery which uses a suitable chemical solution to extract copper content. The chief merits of the wet copper process are:

(1) It can be applied to poor ore with a quite low copper content.
(2) Large quantities can be treated.
(3) Production costs are cheap (provided that there is a ready supply of electric power and iron scrap).

Generally speaking, when the ore used in the wet copper process is a sulphide ore, (i) it is roasted and leached with dilute sulphuric acid to create a solution of copper sulphate; (ii) this is then subjected to chloridizing roasting with salt or some similar substance and a solution of copper chloride is produced through leaching with dilute hydrochloric acid. When the ore used is an oxide ore, (iii) it is treated with a solution such as dilute sulphuric acid or dilute ammonia to take the copper content into solution. The resulting solutions are electrolyzed to produce electrolytic copper, or else scrap iron is added to the solution and the copper content is recovered in the form of precipitated copper, which is then smelted to produce crude copper.

There is also a type of wet copper process utilizing the mine waters found inside copper mines. Because these mine waters normally contain copper sulphate together with sulphuric acid in a free state, the copper content can be recovered in the form of precipitated copper by adding iron scrap to the water.

Another method of copper recovery by means of the wet copper process is heap leaching, which is conducted on a large scale at the Río Tinto mines in Spain. Here, the ore (cupriferous iron sulphide) is heaped up in the open, sprayed with water, and oxidized by the action of the weather; the copper content is thereby transformed into copper sulphate, which is dissolved in large quantities of water, and the copper is recovered by adding scrap iron to the solution. The method of utilizing mine waters is said to have been employed in Europe at Río Tinto from about the sixteenth century, and heap leaching was first used at this same mine in 1752.

The chemical reaction that occurs during the wet copper process as precipitated copper is recovered by means of iron scrap is expressed by the following equation: $CuSO_4 + Fe = FeSO_4 + Cu$ ($Cu'' + Fe = Fe'' + Cu$). This can be explained in the following manner: when iron is soaked in an aqueous solution of chalcanthite, there occurs an electrochemical phenomenon such that, because the ionizing tendency of copper is less than that of iron–i.e., because copper lies below iron in the electrochemical series–iron will displace copper as the iron gradually ionizes and begins to dissolve in the solution, while the copper moves to the surface of the iron.

Chalcanthite is native copper sulphate with five molecules of crystal water ($CuSO_4 \cdot 5H_2O$). In China it has traditionally been called *shidan* 石膽 ('stone vitriol'), and it was known from early times that it could transform iron into copper. For instance, in the *Taiping yulan* 太平御覽 987, "Yaobu" 藥部: "Shiyao" 石藥 we read: "In the *Bencao jing* it says that *shidan* can turn iron into copper" (本草經曰、石膽…能化鐵爲銅). The *Bencao jing* 本草經 here refers to the *Shennong bencao jing* 神農本草經. The *Taiping yulan* 988, "Yaobu": "Shiyao" also quotes the following statement from the *Huainan wan bishu* 淮南萬畢術: "When *baiqing* (basic copper carbonate) comes into contact with iron, the iron turns into copper" (白青得鐵化爲銅). In addition, the *Baopuzi* 抱朴子, "Neipian" 內篇: "Huangbai" 黃白 states that "if one uses *cengqing* (malachite of basic copper carbonate) to smear iron, the iron will turn a red colour like that of copper" (以曾青塗鐵鐵赤色如銅). On the basis of these passages it is to be surmised that knowledge of the wet copper process in China–using both copper sulphate and copper carbonate–goes back to around the end of the Later Han 後漢 or the Wei 魏 and Jin 晉, dynasties (3rd cent.).

Some time later, Shen Kuo 沈括 (1033–97) of the Northern Song 北宋 was to write as follows in his *Mengxi bitan* 夢溪筆談 25:

> In Yanshan county in Xinzhou there is a bitter-tasting spring, the waters of which form a stream. If one takes this water and boils it, it will form chalcanthite, and if one boils the chalcanthite, it will form copper. The cauldron in which the chalcanthite is boiled after a long time also changes into copper.
> 信州鉛山縣有苦泉、流以爲澗、挹其水熬之則成膽礬、烹膽卽成銅、熬膽礬釜久之亦化爲銅。

The statement that the iron cauldron used for boiling the vitriol water changes into copper after a certain period of time probably means that its surface developed a plating of copper, since the iron cauldron would cause precipitation of the copper.

This knowledge of the vitriol copper process, with its extremely long history, was first implemented on an industrial scale in about Yuanyou 元祐 1 (1086) of the Northern Song, when the wet copper process, known as "steeping copper" (*jintong* 浸銅), was developed. This grew on a grand scale, and the vitriol copper thus produced made an enormous contribution to the minting of copper coins during the Northern and Southern Song.

I. The Birth and Development of the Vitriol Copper Process in the Song

(1) The Decline of the Dry Copper Process

During the Song there were both government-operated copper mines and private copper mines. Private mines had to deliver a certain proportion of their production to the government as tax, and this was called a "levy" (*choufen* 抽分). The entire remainder was bought by the government, and this was called "negotiated purchase" (*hemai* 和買). This meant that, together with the copper produced by government-operated mines, the government secured all the copper produced throughout the empire, and it was used as raw material for minting copper coins. In order to meet the demand for coins, which had increased enormously because of the growth of commerce and the development of a monetary economy, great efforts were put into the minting of copper coins. Copper production in the Song peaked during the Xining 熙寧 era (1068–77), when it topped 20,000,000 *jin* 斤 (1 *jin* = approx. 633 gm during the Song). This was probably the largest amount of copper being produced at this time anywhere in the world. In Yuanfeng 元豐 1 (1078) output remained at about 14,600,000 *jin*, but thereafter copper production gradually declined. The reason for this was the exhaustion of existing mines, in particular the decline of Censhui 岑水 mine in Shaozhou 韶州, in Guangnan East 廣南東 circuit, which had earlier accounted for the greatest proportion of China's copper production (87 per cent in Yuanfeng 1). The decline in copper production interferred with the minting of copper coins, and consequently increasing the production of copper became a matter of pressing urgency. But the old mines had been exhausted and new mines were not being opened, and it was at such a time, when both the government and private individuals were searching for ways to increase production, that the wet copper process was devised.

(2) Zhang Qian's "Steeping Copper Method"

The wet copper process was at this time referred to as the "(vitriol water) steeping copper method" ([*danshui*] *jintong fa* [膽水] 浸銅法). It involved the steeping or soaking of iron in vitriol waters to produce copper, and the copper thus produced was called "vitriol copper" (*dantong* 膽銅). In contrast, the copper produced by the earlier method of processing ore, which was fed into a furnace and fired, was called "ore copper" (*kuangtong* 礦銅) or "yellow copper" (*huangtong* 黃銅). When Hong Zikui 洪咨夔 (1176–1236), in his "Daye fu" 大冶賦 (included in the *Pingzhai wenji* 平齋文集), mentions "yellow copper" alongside "vitriol copper" and "leach copper" (*lintong* 淋銅, on which see below), he is in fact referring to "ore copper," or smelted copper.

The steeping method of copper production is described in the following terms in the *Song huiyao* 宋會要, "Shihuo" 食貨: "Zhuqian jian" 鑄錢監. First cast iron is beaten into thin strips, which are then placed in a vitriol water trough and arranged like fish scales. After having been soaked for several days, reddish rust forms on their surface. This reddish rust is scraped off, washed, and fired three times in a furnace, whereupon it becomes copper. The copper thus produced was, namely, vitriol copper.

This steeping method was perfected by a certain Zhang Qian 張潛 of Dexing 德興 county in Raozhou 饒州. He was well-versed in various technologies, and after having discovered a way of turning iron into copper, he wrote it up and had his son Zhang Jia 張甲 present it to the imperial court. According to a passage in the *Changsha zhi* 長沙志 quoted in the *Yudi jisheng* 輿地紀勝 90 in a section on old ruins in Shaozhou in Guangnan East circuit, the government implemented this method at four sites: Yanshan 鉛山 (present-day Yanshan county, Jiangxi 江西 province), Xingli 興利 in Dexing county, Raozhou (present-day Dexing city, Jiangxi province), Yongxing 永興 in Tanzhou 潭州 (present-day Liuyang 瀏陽 county, Hunan 湖南 province), and Censhui in Shaozhou (present-day Shaoguan 韶關 city, Guangdong 廣東 province).

Zhang Qian's work, in one fascicle, was called the *Jintong yaolüe* 浸銅要略, but it is no longer extant. There has, however, survived a preface by Wei Su 危素 of the late Yuan 元 and early Ming 明 (included in the *Wei Taipu wenji* 危太樸文集). According to this preface, this work had an earlier preface dated Shaosheng 紹聖 1 (1094), according to which the compiler Zhang Jia received the work from his father, who is known to have been the great-grandfather of Zhang Dao 張燾, an assistant administrator (*canzhi zhengshi* 參知政事). Wei Su's preface also states that in the year Yuanyou 1 (1086) there were (probably in Dexing county) 32 springs that were used for taking vitriol water and steeping iron and for taking ore and boiling copper, and their precipitation period varied, ranging from five days (one spring) to seven days (14 springs) or ten days (17 springs); there are also said to have been 138 sluiceways for channelling the spring waters.

(3) You Jing's Operations

The two methods of copper recovery–the steeping method and the wet copper process–were first fully described in the *Jintong yaolüe*, and Zhang Qian deserves credit for having consummated the study of these processing methods. However, it was You Jing 游經 who put them into practice and placed operations on an industrial footing. Upon the adoption of Zhang Jia's proposals, You Jing undertook to develop the production of vitriol copper. He established Xingli mine in Dexing county (Raozhou) during the Yuanyou era and Yanshan mine in Yanshan county (Xinzhou) in about Shaosheng 2 (1094), and by Yuanfu 元符 3 (1100) new mines were also being developed in Tanzhou and Shaozhou. You Jing was involved in these operations until about 1106, and as a result of his assiduous efforts he succeeded in increasing the production of vitriol copper.

You Jing employed two methods in his wet copper process–the steeping method using vitriol water (or copper precipitation) and the decocting method using vitriol earth (or copper leaching). It was said that the former, utilizing mine waters, required little labour and was highly profitable, but the supply of vitriol waters was limited, while the latter method was labour-intensive and not very profitable, but the supply of vitriol-bearing earth was unlimited. In order to produce 1 *jin* of copper, 50 *wen* 文 was budgetted for the steeping method and 80 *wen* for the decocting method. In actual practice, You Jing spent 48 *wen* (probably when employing the former method).

In the case of the decocting method, piles of vitriol earth with a copper content were sprayed with water, and the resultant vitriol water was boiled in a furnace. The copper thus produced was called "leach copper." This method was based on the same principle as the steeping method, the only difference being that it involved the additional process of producing vitriol water from vitriol earth. In his "Daye fu" Hong Zikui, as was noted earlier, divides copper into three kinds–yellow copper, steeped copper (or vitriol copper), and leach copper–and with regard to leach copper he vividly describes in florid language how it began at Censhui mine and spread to Yongxing mine and how the vitriol earth was excavated, carted, heaped up into piles, and sprayed with water, whereupon the resulting vitriol water was channelled through sluices and strips of iron were soaked in it.

The leaching sluices were constructed of bricks and fitted with bamboo baskets. The vitriol earth was placed in these baskets, over which water was then poured; it filtered through the earth, and so vitriol water was obtained. According to the *Song huiyao*, "Shihuo": "Kengye zalu" 坑冶雜錄, in Shaoxing 紹興 13 (1143) it was planned to add a further 40 sluices at Yanshan mine to produce 20,000 *jin* of copper. This works out to an average (annual) output of 500 *jin* for each sluice. In addition, the section on Xinzhou in the *Yudi jisheng* 21 states that there were 204 leaching sluices which produced 89,000 *jin* annually, which means that a single sluice produced on average 436 *jin* per year. According to Wei Su's preface to the *Jintong yaolüe*, there were 138 channels fed by the 32 vitriol springs in Dexing county, and therefore it is to be surmised that there were also 138 sluices. This was probably at the height of copper production at Xingli mine in Dexing county (in the late Northern Song), and if we equate its annual production with the quota of 51,029 *jin* for Xingli mine given in the *Zhongxing huiyao* 中興會要, this gives an average annual output of 377 *jin* for each sluice. The figures for the above three mines differ somewhat, but these differences can probably be attributed to differences in the concentration of the vitriol water, the size of the sluices, and technical proficiency, and it would appear that annual average production for a single sluice was about 400 *jin*.

II. Production Costs for Vitriol Copper

(1) Production Costs and Government Purchase Prices

When You Jing first set about producing vitriol copper at Yanshan mine, he spent 44 *wen* per *jin*. This worked out to a little over 600 *wen* for 1 string of cash (*guan* 貫), and this is said to have been a more reasonable outlay than that previously required for minting coins from ore copper (*Song huiyao*, "Shihuo" 34: "Kengye zalu" 25). These figures were those for a mine operated by government officials and manned by soldiers, and so the labour would have been free. In order to assist operations, a preferential capital outlay of 50 *wen* for 1 *jin* of copper obtained by the steeping method and 80 *wen* for 1 *jin* of copper obtained by the decocting method was provided. The production costs for the latter method were greater, but nonetheless they were presumably less than those for ore copper.

At Yanshan mine, it would appear that the assembled miners dug up the vitriol earth and leached it, while soldiers then processed the vitriol water. The government paid miners 250 *wen* for 1 *jin* of (precipitated) copper. This was the situation in the late Northern Song at the start of the twelfth century, and more than 100,000 miners were being employed in these thriving operations. But as commodity prices subsequently rose while the government's purchase price remained unchanged, the miners lost any incentive to work and departed, with the result that in Shaoxing 12 (1142) there remained less than 400 soldiers and the amount of copper recovered had shrunk to 80,000–90,000 *jin*. Accordingly, various measures for boosting production were proposed, and one of these was a proposal to install an additional 40 leaching sluices, which would produce 20,000 *jin* with a capital investment of approximately 18,100 *guan*. It was presumably the construction costs that accounted for the greatest part of this sum, and this means that each sluice cost about 450 *guan* (*Song huiyao*, "Shihuo": "Kengye zalu").

In Qiandao 乾道 1 (1165) the system for supplying the iron needed in the steeping method at Censhui mine was altered. Hitherto iron had been sold to the miners by the government, but it was decided that hereafter the government would supply each miner with a specific quantity of iron determined by the concentration of the vitriol water that he used. If the copper processed by the miner did not reach an amount commensurate with the quantity of iron supplied, the miner would have to pay a sum corresponding to the price of the iron commensurate with the shortfall, thereby guarding against any losses on the part of the government, and the price at which the government purchased copper from the miners was set at 130 *wen* for 1 *jin*. Previously the government had been buying 1 *jin* of ore copper for 220 *wen*, but the quality had been poor, and so even allowing for the price of the iron which it supplied, the vitriol copper was far more advantageous to the government. When taxes (*jingzhi qian* 經制錢 and *zongzhi qian* 總制錢) were deducted and expenses for labour, charcoal, etc., subtracted from the 130 *wen* paid by the government for 1 *jin* of copper, the miners are said to have been left with a net profit of 73 *wen*. In addition, if the copper was of impure quality, the purchase price was reduced proportionately, while those who produced more than their annual quota were paid an additional 40 *wen* per *jin* (*ibid.*).

(2) The Management of Vitriol Copper Mines

The government's purchase price for vitriol copper had bearings on the ways in which the copper mines were managed. In what relation did privately operated mines stand to government-operated mines? It was soldiers and private miners who worked the vitriol copper mines, and three types of mines can be distinguished: fully government-operated mines in which soldiers were responsible for the entire process from digging the vitriol-bearing earth to processing the copper; semigovernmental operations in which soldiers and miners shared the tasks of digging, leaching, and processing; and completely private operations in which miners undertook the entire process.

Under You Jing's management, Yanshan mine was operated as a fully government-run enterprise, with chiefly soldiers providing the labour, and in this case the government covered expenses to the tune of 50 *wen* for 1 *jin* produced by the steeping method and 80 *wen* for 1 *jin* produced by the decocting method. At the height of operations at Yanshan mine, in the late Northern Song, miners dug and leached the vitriol-bearing earth, while the government provided furnaces and soldiers processed the vitriol water, and 250 *wen* was paid for 1 *jin*. But three or four decades later, in Shaoxing 12, when all the miners had departed, only about 400 soldiers remained and annual production fell

80,000–90,000 *jin*. Soldiers were now responsible for the entire copper-producing process, and it became a purely government-run operation. Efforts were made to attract miners by increasing the price paid for copper, but they were unsuccessful, and even in Qiandao 1 (1165) production still stood at only 96,536 *jin*. Because of the failure to attract more miners, the mine was presumably operated solely with labour provided by soldiers.

At Censhui mine, miners were responsible for the entire process in the case of the steeping method, while in the case of leach copper soldiers (attached to Guangdong and Guangxi 廣西 circuits) brought the vitriol earth from the summit of a remote mountain. It was, in other words, a semigovernmental operation. The soldiers were supplied with food and clothing, but these supplies tended to be inadequate. In Qiandao 1 the regulations were changed, and they were given a daily rice ration of 2.5 *sheng* 升. This was in line with the treatment of soldiers at Yanshan mine. In addition, the purchase price for copper was also raised at this time to 130 *wen* for 1 *jin*, and the system of supplying the iron needed for the steeping method was also introduced.

(3) The Provision of Iron

Iron is necessary for the steeping method of copper production. At Xingli mine in Raozhou and Yanshan mine in Xinzhou, 2.25 *jin* of iron were consumed for every *jin* of copper produced (entry for cyclic day *xinmao* 辛卯, 10th month, Shaoxing 2, in *Jianyan yilai xinian yaolu* 建炎以來繫年要錄 59). In the case of Censhui mine in Shaozhou, it is said that 200,000 *jin* of copper were produced from 1,000,000 *jin* of iron, which means that 1 *jin* of copper required 5 *jin* of iron (Zhang Duanyi 張端義, *Guier ji* 貴耳集 3). This was probably during the reign of Lizong 理宗 (1224–64) of the Southern Song. The ratio of iron to copper was thus more than twice that at Xingli and Yanshan mines, and this was probably due to differences in the concentration of the vitriol waters.

Every effort was made to ensure a constant supply of iron. The iron mines in Guangdong circuit were all under the control of the Fiscal Commission (*zhuanyun si* 轉運司), but newly opened mines were placed under the control of the Copper Bureau (*cuozhi tongshi si* 措置銅事司), which was in charge of operations relating to the production of vitriol copper. In Yuanfu 3 (1100), after this agency had been abolished, the Mint (*zhuqian si* 鑄錢司) was compelled to defray copper funds (*tung benqian* 銅本錢) for the purchase of the copper used for minting coins, and with these funds iron was bought for use at Censhui mine. According to a passage for the twelfth month of Zhenghe 政和 6 (1116) in the *Songshi* 宋史 185, "Shihuo zhi" 食貨志: "Kengye" 阬冶, the iron mines in Guangnan East circuit produced more than 2,890,000 *jin* of iron annually at 92 sites, and this was all bought up by officials for use in the steeping method of copper production. The officials at copper-processing sites sold this iron to the miners, who then produced the copper, but, as was noted earlier, in Qiandao 1 it was decided to supply the miners with a fixed quantity of iron determined on the basis of the concentration of the vitriol waters that they used. A report submitted by the Mint in the seventh month of Qiandao 2 (1166) states that the iron produced by the iron mines in all circuits was used exclusively for producing copper by the steeping method (*Song huiyao*, "Shihuo" 33: "Kengye"). The copper-processing sites for which the iron was destined and the quantities sent are listed below. (The figures in parentheses represent the amount of copper produced.)

Yanshan mine (Xinzhou): 415,320 *jin* (96,536 *jin*)

Xinzhou: Yanshan, Shangrao 上饒, Yiyang 弋陽, Yushan 玉山, Guixi 貴溪; Fuzhou 撫州: Dongshan *chang* 東山場; Jianning *fu* 建寧府: Pucheng 浦城 (Renfeng *chang* 仁風場; Chuzhou 處州: Lishui 麗水, Qingtian 青田.

Yanshan mine (Xinzhou) and Xingli mine (Raozhou): 64,186 *jin* 13 *liang* 兩

Chizhou 池州 Guichi 貴池; Longxing *fu* 隆興府: Jinxian 進賢; Jiangzhou 江州: De'an 德安; Xingguo *jun* 興國軍: Daye 大冶; Shuzhou 舒州: Huaining 懷寧; Chenzhou 辰州: Xupu 敘浦, Chenxi 辰溪.

Xingli mine (Raozhou): 18,223 *jin* (23,483 *jin*)

Raozhou: Dexing 德興, Poyang 鄱陽", Yugan 餘干, Fuliang 浮梁, Yueping 樂平; Huizhou 徽州: Wuyuan 婺源.

Censhui mine (Shaozhou): 365,630 *jin* 8 *liang* (88,948 *jin*)

Jizhou 吉州: Anfu 安福 (Lianling *chang* 連嶺場), Luling 廬陵 (Huanggang *chang* 黃崗場), Jishui 吉水, Wan'an 萬安; Shaozhou: Wengyuan 翁源; Nanxiongzhou 南雄州: Shixing 始興; Guangzhou 廣州: Zengcheng 增城, Panyu 番禺, Jiyuan 濟遠, Huaiji 懷集; Huizhou 惠州: Boluo 博羅; Yulinzhou 鬱林州: Nanliu 南流; Binzhou 賓州: Qianjiang 遷江.

Yongxing mine (Tanzhou): 13,059 *jin* (3,414 *jin*)

Tanzhou: Liuyang 瀏陽, Shanhua 善化.

Tongling 銅陵 county (Chizhou 池州): 3,645 *jin* 8 *liang* (408 *jin* 5 *liang*)

Chizhou: Tongling.

Grand total: 880,064 *jin* 13 *liang* (212,789 *jin* 5 *liang*)

According to these figures, approximately 4 *jin* of iron were necessary to produce 1 *jin* of copper. When iron was in short supply, the production of vitriol copper inevitably fell, and the chief reason for the decline in the production of vitriol copper in the Southern Song was a shortage of iron.

III. The Output of Vitriol Copper

(1) Figures for Chongning 5 (1106)

The *Shantang qunshu kaosuo houji* 山堂群書考索後集, "Caiyong men" 財用門:

"Tongqian lei" 銅錢類 quotes a report drawn up by the Secretariat (*zhongshu sheng* 中書省) in Chongning 崇寧 5 (1106), according to which more than 6,600,000 *jin* of copper of various kinds were acquired each year. This copper consisted of about 4,600,000 *jin* from existing copper mines, 1,000,000 *jin* of vitriol copper, and 700,000 *jin* of *chatong* 碴銅. Copper from existing copper mines corresponded to smelted copper (or "yellow copper"), while *chatong*, judging from the gloss in the original text (治料淘尋到即不常有), represented extraordinary revenue, probably deriving from the steeping method of copper production. These figures represent the output for the previous year (Chongning 4), which was then totalized and reported by the Secretariat in the subsequent year. This means that, of the copper produced in Chongning 4, 4,600,000 *jin* were produced by the dry process and 170,000 *jin* by the wet process.

(2) Output in the Late Northern Song and Qiandao 2

The standard production or quota figures given in the *Zhongxing huiyao* probably represent the annual results for the late Northern Song. In the following table these have been compared with the figures given in a report drawn up by the Mint in Qiandao 2 (1166) of the Southern Song (which are in fact the production figures for the previous year 1165); *Song huiyao*, "Shihuo" 33: "Kengye", Manuscript of the Toyo Bunko). ('K' stands for *kuangtong* 礦銅 ["ore copper" or smelted copper] and 'D' stands for *dantong* 膽銅 [vitriol copper]; here and in the following tables units are in *jin* and *liang* unless otherwise stated.)

(3) Vitriol Copper and Fluctuations in Copper Production

Next, let us compare the above circuit production figures with their outputs for Yuanfeng 1 (1078) (*Song huiyao*, "Shihuo" 33).

The total production in II has fallen to about half of that in I, while that in III has shrunk to less than 4 per cent of that in II. The Southern Song had lost the northern half of its former territory, but since this did not include the main copper-producing regions, the reason for this sudden decline in production lay in a slump in mining due to the exhaustion of mineral resources. Moreover, were one to exclude vitriol copper from the above figures, production in III would have been a mere 0.7 per cent of that in II, and so it was only because of vitriol copper production that an output of just under 4 per cent was achieved.

If we now compare individual circuits in I and II, we find that the main circuits to show a decline in production were Guangnan East, Fujian 福建 and Liangzhe 兩浙, while the chief circuits to increase production were Jiangnan East and Jinghu South 荊湖南. The increased production in Jiangnan East was in vitriol copper, while the production of both smelted and vitriol copper rose

Circuit	Location of Copper Mines	Production: Quota in *Zhongxing huiyao*	Production: Qiandao 1	Directorate of Coinage
Jiangnan East	Raozhou Xingli *chang*	D: 51,029-8	D: 23,483	Raozhou
	Xinzhou Yanshan *chang*	D: 380,000	D: 96,536	Raozhou, Yanzhou
	Xinzhou Baofeng *chang*	K: 2,000	K: 40	Raozhou
	Chizhou Tongling *xian*	D: 1,398	D: 408-5	Raozhou
Jiangnan West	Xingguo *jun* Daye *xian*	K: 1,400		
Guangnan East	Shaozhou Censhui *chang*	K: 3,164,700	K: 20,440	Shaozhou, Raozhou, Ganzhou
	Shaozhou Censhui *chang*	D: 800,000	D: 88,948	
	Lianzhou Yuanyu *chang*	K: 109,260	K: 2,880	Shaozhou
Jinghu South	Tanzhou Yongxing *chang*	K: 1,796,000		
	Tanzhou Yongxing *chang*	D: 640,000	D: 3,414	Raozhou
Fujian	Tingzhou Changting *xian*	K: 62	K: 62	Jianzhou
	Nanjianzhou Youxi *xian*	K: 69,958	K: 3,654	
	Nanjianzhou Jianpu *xian* Dayan *chang*	K: 8,190		
	Jianning *fu* Pucheng *xian* Yinjiang *chang*	K: 28,800	K: 8,317-4	
	Jianning *fu* Chongan *xian*	K: 1,140		
	Shaowu *jun* Guangze *xian*	K: 325	K: 325	
Liangzhe	Wuzhou Yongkang *xian*	D: 2,000		
Sichuan	Tongchuan *fu* Tongshan *xian*		K: 6,000	
	Lizhou Qingni *chang*		K: 7,000	Raozhou
	Xingzhou Qingyang *chang*		K: 1,662	
	[Total]	K: 5,181,835 D: 1,874,427-8	K: 50,380-4 D: 212,789-5	
	[Grand Total]	7,057,263-8	263,169-9	

Circuit	I: Yuanfeng 1	Ranking	II: Quota in *Zhongxing huiyao*	Ranking	III: Qiandao 1	Ranking
Jiangnan East	1,608		K: 2,000 D: 432,427	3	K: 40 D: 120,427	1
Jiangnan West	130		K: 1,400	6		
Guangnan East	12,808,430	1	K: 3,273,960 D: 800,000	1	K: 23,320 D: 88,948	2
Jinghu South	1,082,684	2	K: 1,796,000 D: 640,000	2	D: 3,414	4
Fujian	380,542	3	K: 108,475	4	K: 12,358	3
Liangzhe	47,511	5	D: 2,000	5		
Sichuan	277,693	4			K: 14,662	5
Total	14,605,969		7,057,263		263,169	

in Jinghu South.

As for the circuits' rankings, the positions of the first-placed Guangnan East and second-placed Jinghu South remained unchanged. But it is noticeable that the formerly low-ranking Jiangnan East circuit rose to third place. In sum, the most striking feature of these figures is the overall decline in the production of smelted copper and an increase in vitriol copper production.

Moving from II to III, we find that the production of both smelted copper and vitriol copper has fallen sharply, but the decline in the production of smelted copper was far greater than that of vitriol copper. At the start of the Southern Song, almost all mines and smelteries went to ruin as a result of the nationwide upheavals that occurred at this time, and in the third month of Shaoxing 2 (1132) all mines and smelteries whose income was insufficient to cover their expenses were closed. The reason that the sites in Raozhou and Xinzhou were especially authorized to continue operating was that they produced vitriol copper.

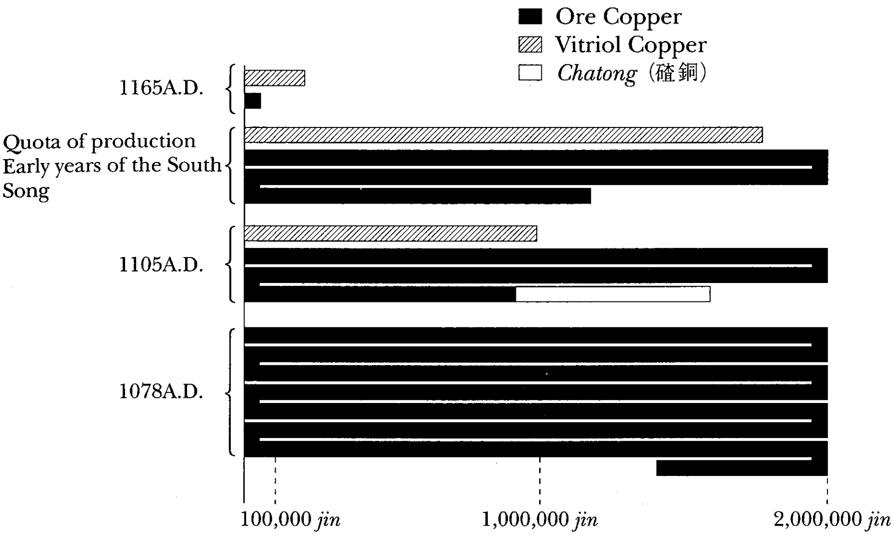
The circuit figures for Qiandao 1 show that Guangnan East and Jinghu South suffered a spectacular decline in production, while the decline in Jiangnan East was comparatively small because most of its production was in vitriol copper, and its output now surpassed that of Guangnan East, which had since the Qingli 慶曆 era (1041–48) of the Northern Song been unrivalled in copper production. Among individual sites, Censhui mine, which had in Yuanfeng 1 accounted for 87 per cent of China's recorded copper production, still managed to rank first with 41.5 per cent, followed by Yanshan mine with 36.4 per cent and Xingli mine with 8.9 per cent. Thus the national distribution of copper production underwent a complete change on account of vitriol copper production. Changes in the ratio of smelted copper to vitriol copper in national production figures can be seen in the following table.

	Chongning 4	Quota in *Zhongxing huiyao*	Qiandao1
Smelted Copper	5,600,000	5,181,835	50,380-4
Vitriol Copper	1,000,000	1,874,427-8	212,789-5
Ratio of Vitriol Copper to Smelted Copper	1:5.6	1:2.76	1:0.24

This table shows that there was a steady decline in the ratio of smelted copper to vitriol copper, while the proportion of vitriol copper in total output steadily rose, and by Qiandao 1 their positions had been completely reversed.

(4) Vitriol Copper Production after the Qiandao Era

There are no adequate records of copper production after Qiandao 2, and so the ratio of smelted copper production to vitriol copper production is not



Copper Production in the Song

known. The projected copper production in Qiandao 9 (1173) was one third higher than that produced in Qiandao 2. This projected increase by one third represented about 88,000 *jin* and was based on the results of the foregoing years, presumably due to increased production in Chuzhou and at Censhui mine.

In about Qiandao 8, 100 additional sluices were installed at Censhui mine for use in the steeping method of copper production. If we assume that each sluice produced 400 *jin* of vitriol copper annually, this translates into an additional annual production of 16,000 *jin*. Digging at the copper mines in Chuzhou (in Eastern Liangzhe circuit, corresponding to present-day Lishui county, Zhejiang 浙江 province) began in Qiandao 7 (1171), when officials were sent to oversee operations, and thereafter they produced about 45,000 *jin* of copper annually, reaching 100,000 *jin* in Chunxi 淳熙 2 (1175). But these mining operations did not continue for very long, and little more than a decade later they appear to have gone into decline. Most of the copper produced in Chuzhou was smelted copper, but some vitriol copper was also produced.

During the Southern Song, vitriol copper production was consistently higher than smelted copper production, but the production of vitriol copper also gradually declined. Zhou Hui 周煇 of the Southern Song writes in his *Qingbo zazhi* 清波雜志 that in recent years (i.e., the second half of the twelfth century) the stream of vitriol water at Yanshan had almost stopped flowing, and consequently the steeping method required more labour. The *Yudi jisheng* 21 notes that at the start of the thirteenth century the 204 leaching sluices at Yanshan mine produced 89,000 *jin* of copper annually. This figure represents a drop of about

7,500 *jin* in comparison with Qiandao 2. In addition, according to Zhang Duanyi's *Guier ji* 3, 1,000,000 *jin* of iron were used at Censhui mine to produce 200,000 *jin* of copper, which indicates that in the mid-thirteenth century the annual production of vitriol copper at Censhui mine was 200,000 *jin*. This represents a decrease of about 69,000 *jin* when compared with Qiandao 2. Thus, in view of the fact that the output of the main sites of vitriol copper production fell during this period, it is to be surmised that during the reigns of Ningzong 寧宗 and Lizong in the second half of the Southern Song (that is, the first half of the thirteenth century) the production of vitriol copper gradually declined in comparison with Qiandao 2. But the predominance of vitriol copper production over smelted copper production remained unchanged.

(5) Vitriol Copper and Minting during the Southern Song

Using the copper obtained in this manner, the Southern Song government only just managed to continue the minting of copper coins. The following table compares the numbers of strings of cash (*guan*) minted in different years during this period, and it is evident that generally somewhat more than 100,000 strings of cash were produced. This represents a dramatic fall when compared with the Northern Song's highest single-year total of 5,600,000 in Yuanfeng 2 (1079). But the fact that the minting of coins was nonetheless able to continue, albeit on a smaller scale, was mainly due to the production of vitriol copper.

Year	Strings of Cash Minted	Remarks	Source
Shaoxing 1-2	200,000	Actually minted	*Shantang kaosuo houji* 60
Shaoxing 25	100,000	Actually minted	*Yuhai* 180
Shaoxing 26	145,000	Actually minted	*Ibid.*
Shaoxing 31	101,000	Actually minted	*Zhongxing xiaoji* 40
Shaoxing 32	104,000	Actually minted	*Shantang kaosuo houji* 60
Qiandao 1	113,500	Actually minted	*Ibid.*
Chunxi 3	150,000	Yearly quota	*Songshi* 180, "Shihuo zhi"

By the late Southern Song, some of the copper coins minted using vitriol copper were of poor quality and lacked durability. This was probably because of the presence of high levels of iron in the minting alloy.

IV. The Wet Copper Process in the Post-Song Period

The Southern Song was succeeded by the Yuan dynasty. Because the Yuan government initially used paper money and did not mint copper coins, there was little need for copper, and it would seem that the steeping method of copper production was abandoned. However, in Zhida 至大 3 (1310) during the reign of Wuzong 武宗 there was a change in monetary policy, resulting in the introduction of a coinage system and the minting of copper coins known as the "Zhida coins" (*Zhida tongbao* 至大通寶). A supply of copper thus became necessary, and the steeping method made a comeback.

Zhang Mao 張懋 and Zhang Ti 張逖, both descendants of Zhang Qian, who had perfected the steeping method of copper production in the Northern Song, submitted his *Jintong yaolüe* to the imperial court with the request that the steeping method of producing copper be resumed. Their proposal was adopted, a processing site was established, and the Zhangs were placed in charge, but the project was unsuccessful and the site was closed (Wei Su, "Preface to *Jintong yaolüe*").

However, there was one further occasion during the Yuan dynasty when the steeping method of copper production took centre stage. Several decades after Zhida 3, during the reign of Shunzong 順宗, reform of the monetary system once again came up for discussion, and Zhang Ti's son Zhang Li 張理 again submitted the *Jintong yaolüe* to the court with the proposal that the steeping method be implemented at Dexing in Raozhou in order to ensure a supply of copper as raw material for minting coins. The grand councillor, considering this plan to have economic merit, adopted it, and in the third month of Zhizheng 至正 12 (1352) the Xingli mine in Raozhou was revived and placed under the direct control of the Supervisorate of Coinage (*baoquan tiju si* 寶泉提舉司), with Zhang Li being appointed manager of the copper smeltery ("Preface to *Jintong yaolüe*"; *Yuanshi* 元史 42, "Shunzong benji" 順宗本紀). But although Zhang Li set about his assigned task of processing copper, operations again proved unsuccessful and the smeltery was closed (*Dushi fangyu jiyao* 讀史方輿紀要 85).

The Zhang family of Dexing was a distinguished local family, renowned for many generations as a family of learned scholars, and many family members entered government service. On the basis of various sources, their genealogy can be reconstructed as follows:

Zhang Qian ┬ Pan 盤 ┬ Gen 根 — Dao 燾 — Yan 埏 ┬ □ —— Ti 逖 — Li 理
　　　　　└ Jia 甲 ├ Pu 樸　　　　　　　　　　└ Mao 懋
　　　　　　　　　└ Mo 模

Among the above members of the Zhang family, Gen became a metropolitan graduate (*jinshi* 進士) in Yuanfeng 5 (1082) and rose to the position of fiscal commissioner (*zhuanyun shi* 轉運使) of Huainan 淮南, and he was also a prolific writer, authoring the *Songchao biannian* 宋朝編年 in several hundred fascicles and a number of other works as well. Pu became a metropolitan graduate in Daguan 大觀 3 (1109) and rose to vice-director of the Palace Library (*mishu shaojian* 秘書少監), while Dao became a metropolitan graduate in Zhenghe 8 (1118) and in Longxing 隆興 1 (1163) attained the high position of assistant administrator. It was by such a family, with distinguished traditions, that the steeping method of copper production was transmitted and preserved.

Next, during the Ming dynasty, the steeping method was employed at Dexing and Yanshan mines in Jiangxi around Xuande 宣德 3-4 (1428–29), producing more than 5,000 *jin* of copper annually; the necessary iron and charcoal had to be supplied by the miners themselves (*Xuande shilu* 宣德實錄). From the mid-Ming through to the Qing 清 the copper mines in Yunnan 雲南 and elsewhere in the southwest became the main copper-producing sites, with all copper being processed by the dry method employing smelting furnaces, and the wet copper process fell into oblivion.

However, although the wet copper process disappeared from the mining and manufacturing industries, knowledge of the steeping method was not lost and continued to be passed down during the Ming and Qing dynasties. References to it can be found, for instance, in the following works from the late Ming: Li Shizhen's 李時珍 *Bencao gangmu* 本草綱目 8, "Jinshi" 金石: "Chitong" 赤銅, quoting from the *Baocang lun* 寶藏論; Xie Zhaozhi's 謝肇淛 *Wuzazu* 五雜組 3, "Dibu" 地部; and Fang Yizhi's 方以智 *Wuli xiaoshi* 物理小識 7.

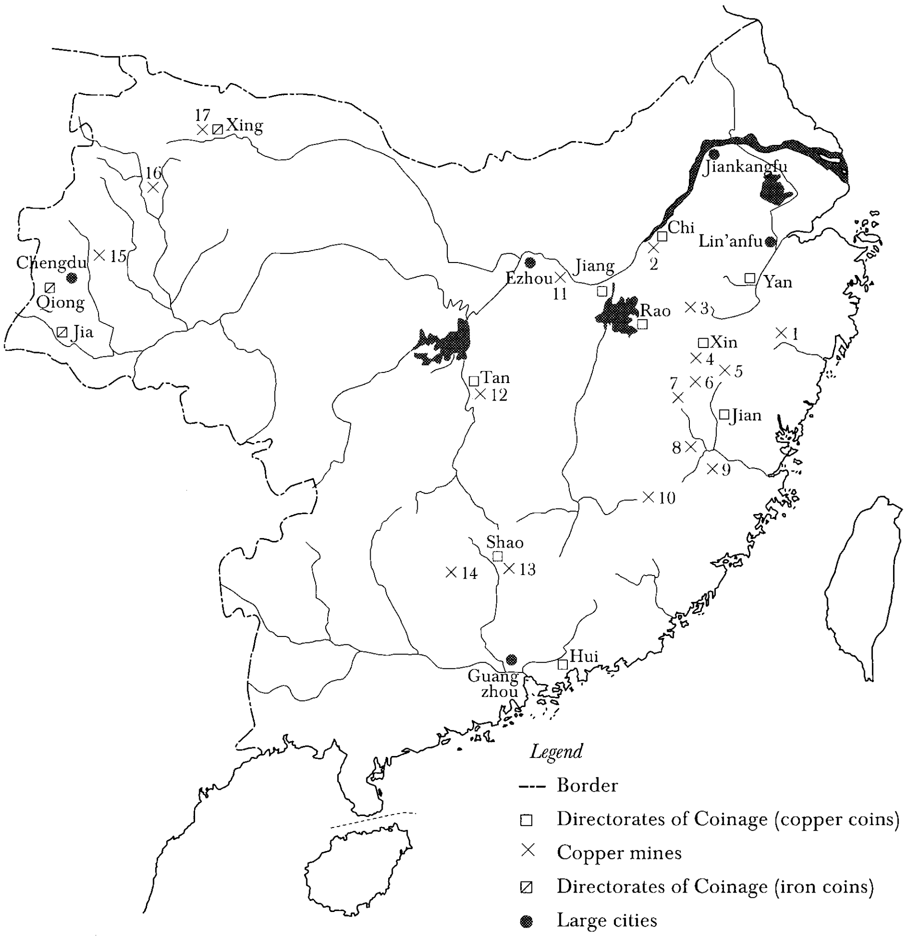
Concluding Remarks

The generation of copper by means of the wet process was already known in the period from the final years of the Later Han through to the Wei and Jin dynasties, but it was only in the Northern Song, during the Yuanyou era, that this process came to be implemented on an industrial scale, with two methods—using mine waters and heap leaching—being employed. Because the production of copper by the dry method was in decline at this time, thereby making it difficult to satisfy the need for a source of raw material for use in the minting of coins, efforts were made to meet by means of the wet copper process the demands for a secure supply of copper for the minting of copper coins.

Once the Song fell and was succeeded by the Yuan, the monetary system changed to one making exclusive use of paper money, and consequently there was no longer any need for copper as raw material for copper coins. The wet copper process was thus on the verge of being forgotten, but in the late Yuan coins were reintroduced and moves were once again made to industrialize this process, but without success.

During the Ming and Qing the copper required as raw material for minting copper coins was produced primarily by the dry process, and the industrial application of the wet copper process disappeared completely, with knowledge of this process being preserved only in a number of written works. Thus China's wet-process-based copper mining industry eventually came to an end without having been developed to its full potential. This presents an intriguing contrast with the continuing operations and prosperity of the Río Tinto mines in Spain, where mine waters began to be utilized in the sixteenth century and heap leaching was introduced only in the eighteenth century.

Principal Directorates of Coinage and Copper Mines during the Southern Song (cf. Table on p. 11)



Key to Map

1 Wuzhou Yongkang *xian* 婺州永康縣
2 Chizhou Tongling *xian* 池州銅陵縣
3 Raozhou Xingli *chang* 饒州興利場
4 Xinzhou Yanshan *chang* 信州鉛山場
5 jianning *fu* Pucheng *xian* Yinjiang *chang* 建寧府浦城縣因將場
6 Jianning *fu* Chongan *xian* 建寧府崇安縣
7 Shaowu *jun* Guangze *xian* 邵武軍光澤縣
8 Nanjianzhou Jianpu *xian* Dayan *chang* 南劍州劍浦縣大演場
9 Nanjianzhou Youxi *xian* 南劍州尤溪縣
10 Tingzhou Changting *xian* 汀州長汀縣
11 Xingguo *jun* Daye *xian* 興國軍大冶縣
12 Tanzhou Yongxing *chang* 潭州永興場
13 Shaozhou Censhui *chang* 韶州岑水場
14 Lianzhou Yuanyu *chang* 連州元魚場
15 Tongchuan *fu* Tongshan *xian* 潼川府銅山縣
16 Lizhou Qingni *chang* 利州青泥場
17 Xingzhou Qingyang *chang* 興州青陽場