# Mining and Metallurgical Technology

**Jueming Hua**

## 1 Foreword

In ancient China, people extracted copper, gold, tin, lead, iron, silver, mercury, and zinc from their ores for daily use. Perhaps they obtained stibium in the same way. Stibium in China mainly originated in Xinhua, Hunan Province, where it was known to have been extracted during Ming Dynasty. But at that time, it was mistaken for tin, thus the place of its extraction was called tin mine, which is now the place where Shuikoushan Mining Bureau is situated. As stated in Shuo Wen Jie Zi (Origin of Chinese Characters), all metals belong to the family of gold, hence came the Chinese phrase Jinshu (categorized into gold), which is given "metal" as the English equivalent.

Of the above-mentioned metals, copper and iron were regarded as the most important. It was only in China that series of bronze sacrificial vessels (generally referred to as Yi device) were possibly made and the techniques for iron smelting could be used for as long as 2,000 years. Bronze and iron each held the leading position among metals for 2,000 years in China, thus having helped establish the well-known magnificent bronze civilization in the Shang and Zhou Dynasties and the grand Chinese iron civilization ranked long among the first rate in the world.

Then, we would like to ask the following questions: How was copper smelted? How iron and steel was produced? What kind of civilization had bronze and iron helped create? Where and how significant were they placed in the history of the world civilization? Does this civilization still exist today? How meaningful is that to us if it still remains?

J. Hua (✉)
Chinese Academy of Sciences, Beijing, China



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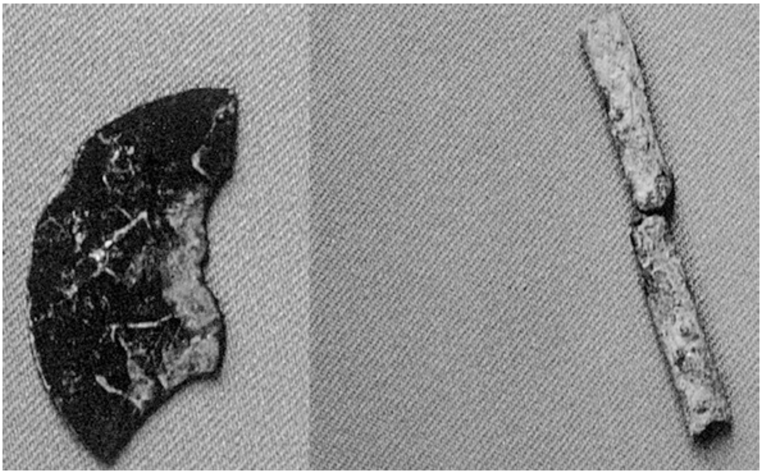

**Fig. 1** A brass sheet and a brass tube

## 2 Historical Stages of Mining and Metallurgy in China

### *2.1 Stage of Emergence of Metallurgical Technology*

The earliest metallic relics hitherto known in China are the brass sheet and tube (See Fig. 1) excavated at the site of Jiangzhai, Lintong, Shaanxi Province. Made from a mixture of copper and zinc, these brass items were produced around 3500 BC when Yangshao Culture was in its late stage about 5,500 years ago. As the test shows, the brass sheet is cast form and about 1 mm thick, zinc takes up nearly 25 % in content; the tube formed by curving, zinc takes up about 32 %. Then, later some brass bits were found on the remnants of crucibles in Yuci, Shanxi Province, and also some original brass was unearthed in Weinan, Shaanxi Province. From the data available, we get an impression that the metallic relics indicating the late stage of Yangshao Culture till the early stage of Longshan Culture in the Central Plains and the remote and bordering areas of China seemed to appear and disappear now and then, and they were mostly discovered by chance. So, we could say that the stage of the emergence of metallurgical technology was characterized by the toughness of getting an undertaking started, which was inevitably a feature in the invention of metallurgical technology.

### *2.2 Stage of Using Both Stone and Copper in Daily Life*

The late Neolithic Age, about 4,500–5,000 years ago, was a period of times when stone and copper were both used in daily life. During that period, metallic products, widely used in Henan, Hebei, Shandong, Gansu, Qinghai, Liaoning, and Inner-Mongolia, were mostly small instruments like drills, chisels, knives, and peeling devices, and ornaments like earrings and hair wares that were made from copper, original brass, etc., by way of forging and casting.

## *2.3 Stage of Making Bronze Instruments*

The time from the Xia Dynasty through Spring and Autumn and the Warring States Periods was a period when bronze instruments were made and used. As the saying goes in Zuozhuan, the most important thing for a country and its people was to hold ceremonies worshiping their ancestors and therefore rites, music, arms, and vehicles as well as plates and vessels (See Fig. 2) for daily use were given high priority. But bronze instruments, as a key element in productive force, were playing a more fundamental role although it was barely given enough attention.

## *2.4 Stage of Casting Ironware*

The period of casting ironware was from the Warring States Period to the Qing Dynasty. The Cangzhou iron lion (See Fig. 3) is a representative of extra-large iron castings, which, 5.3 m long, 5.4 m tall, 3 m wide, and weighing 40 tons, was cast in the third year of Guangshun (953 AD), later Zhou Dynasty of Five Dynasties,

**Fig. 2** A double-sheep Zun (a wine vessel) produced in Xia Dynasty, excavated in Yanshi, Henan Province

**Fig. 3** Cangzhou iron lion produced during Five Dynasties

by using more than 400 mud modes. No wonder Joseph Needham said that by the Fifteenth century only China had so plentiful iron resources.

# 3 Lecture 1 Copper Metallurgy

## *3.1 Copper Mining and Smelting*

### 3.1.1 Copper Source in Shang and Zhou Dynasties and Investigation and Excavation of Ancient Copper Mining and Smelting Sites

Bronze instruments were made and used in China over Seventeenth centuries, from Xia Dynasty to the Spring and Autumn and Warring States Periods, with a huge amount of copper consumed. But there were no large copper mines in Yin Ruins, Zhouyuan, Luoyi, and their surrounding areas. In the 1930s, Li Ji and Shi Zhangru raised the question about the source of copper used in Shang and Zhou Dynasties, and the question has drawn great attention from academic circles. By investigating it for years, the author proposed in the 1980s that through a comprehensive multi-disciplinary study the question could be answered by considering the following three aspects.

1. The copper mines indicated in the historical records. Shangshu–Yugong states that Yangzhou situated between Huaihe River and Haihe River was a place where the tributes paid to the imperial court included gold, silver, and copper (See Fig. 4). It is said in Kaogongji that there was copper and tin in Wuyue (today's Yangzhou), and in Yuejueshu, it is also mentioned that Jiangnan (today's Jingzhou) had copper and tin. So, Yangzhou and Jingzhou are the most frequently mentioned places where copper is produced.
2. The copper resources and old copper mines are known through the explorations in modern times, such as Tonglvshan mine in Daye, Tongling mine in

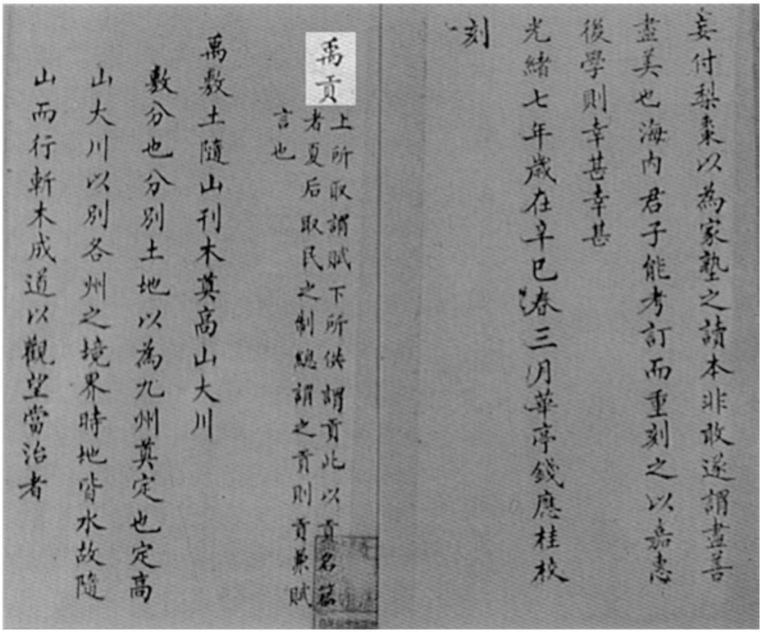

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**Fig. 4** Photocopy of *Yugong*

Ruichang, and Tongguanshan mine in Tongling. In almost all the copper mining areas explored in modern times, there have been found remains of shafts and galleries used in copper mines in ancient times.

3. The third item is about excavation and study of the ancientry mining and smelting site, which is the most important and most difficult to be done. By chance, in 1975, was found and excavated Tonglvshan copper mining and smelting site in Daye, whose copper deposits, according to the test, started to be excavated in the early Western Zhou Dynasty. The Tongling copper mining and smelting site in Ruichang, which was found in 1988, was started in operation in the middle of Shang Dynasty, and the age of its pit lumber, according to the fourteenth century dating technique applied to it, is 3330 ± 60 now. The above-mentioned two sites belonged to the areas of Jingzhou in ancient times, while the remnant copper mining and smelting sites in Wannan belonged to the areas of Yangzhou in ancient times. Tongguanshan copper mining and smelting site were excavated in the 1950s, but plenty of its remnants and remains were destroyed or lost because of our unawareness of relic preservation. According to Wang Yumin, general engineer of Tongling Nonferrous Metal Company, the remnants, and remains excavated from Tongguanshan copper mine were similar to those from Tonglvshan copper mine in kinds and amounts, including a lot of shafts, pit lumber, copper and iron tools, bamboo baskets, wooden shovels, winches, canoes, etc. Through exploring places from Anqing to Maanshan in the 1980s were found more than 20 ancient copper mining and smelting sites

> where many shafts and furnaces were excavated later on. The copper mines in Zhongtiao mountainous area stretched from Yuanqu, Yuncheng till Yongji, and on the other side of the Yellow River were copper mines of the Weihe River Basin stretching from Xi'an city to Huayin county. In Shiji–Xiaowu Benji, it is stated that Emperor Huang ordered copper be mined from Shoushan and pots be cast from copper at the foot of Jingshan. Here, the mentioned Shoushan is in Yongji, Shanxi Province, and Jingshan at Lingbao, Henan Province, known as an ancient site for pot casting. And, Zhongtiao Mountain was called Gudengshan in ancient times. So, the source of copper used for copperware casting in Shang and Zhou Dynasties mainly came from Gudengshan in the north and Jingyang in the south.

Copper resources played an important role in the early development of Chinese civilization. As one of the places of origin for the Chinese nation, Fenhe River Basin in the south of Shanxi Province was rich for its agricultural resources. For instance, Jishan County was where Houji, the god in charge of agriculture in ancient Chinese legends, was born and worked, and it also had copper mines and salt lakes thus being a place suitable for Chinese ancestors breeding and multiplying. Linfen was the capital when Emperor Yao ruled. Lishan was the farmland when Emperor Shun ruled. Dayudu (where Dayu stopped when he was traveling for regulating rivers and water resources in China) is to the south of Yuncheng. Many other important ancient sites were found in this area, such as Taosi (the palace of Emperor Yao 4,000 years ago) in Xiangfen, and Dongxiafeng Village (having remnants of Longshan Culture) in Xiaxian. Then, State Wei established its capital in Xinjiang, and its nobility's cemetery was built in Quwo. And in Houma was discovered a very large ancient copper smelting and casting site.

Copper in ancient times was a kind of very important strategic material, similar to petroleum today, thus fights for it were frequent and severe. In Book of Songs • Odes to Lu, it is stated that the tribes inhabiting the Huaihe Basin had awareness to show their loyalty to King Luxigong by offering tributes including treasures, turtle shells, elephant teeth, and copper. Also on the Caihou Ding (a pot named after Lord Cai) is inscribed the words "Lord Cai conquered Chaohu area and obtained a lot of copper." Zhang Guangzhi believes that in Xia, Shang, and Zhou Dynasties, capital site selecting was associated with whether it was convenient to get access to copper resources. For example, Panlong city at Huangpi, Hubei Province, only 100 km away from Tonglvshan copper mine, might have been where an agency of the Shang royal court was situated with a view to get access to copper mined from ancient Jingzhou including Yangxin, Hubei Province, and Mayang, Hunan Province. According to the lead isotope ratio test (208/207, 208/206), some of the copper used in Yin Ruins, Baoji, Shaanxi Province, and Xingan, Jiangxi Province was taken from Tongling mine and Tonglvshan mine. But all the above mentioned is only a preliminary investigation, and we need further research on the ancient copper mining and smelting sites in Zhongtiao mountainous area.

### 3.1.2 Copper Mining

In early times, stone hammers and stone drills were used for tunneling, together with crushing rocks by blasting. Afterward, bronze tools like adzes and axes were used. The bronze axe excavated in the remaining site of Tonglvshan mine weighs 16 kg (See Fig. 5), so it might have been hanged when used to hit the surface of the work. And then, during the Warring State Period, iron tools replaced all bronze tools.

Copper mines along the middle and lower reaches of Yangtze River were in a broken belt. To ensure mining copper normally, a lot of wood supports were used. The supports were then developed into a series of products produced by first making components on the ground and then assembling them underground (See Fig. 6). That was very convenient. The pit shafts used in Western Zhou Dynasty were about 0.6 m wide, and the miner had to work thereby crawling forward. The ones used during the Warring States Period were more than 1 m wide so that the miner could stand straight working there. In early times, pit shafts were supported by using separate braces. Afterward, they were supported by stacked disks, forming a closed support. The walls of the pit shaft were held with wood plates.

In the walls of the tunnel, there were niches chiseled where oil lamps or lighted bamboo sticks were placed to illuminate the tunnel. The tunnel was ventilated by the flow of wind caused by the drop between different horizontal surfaces. Water was

**Fig. 5** A bronze axe produced in the Spring and Autumn period, unearthed in the remaining site of Tonglvshan mine

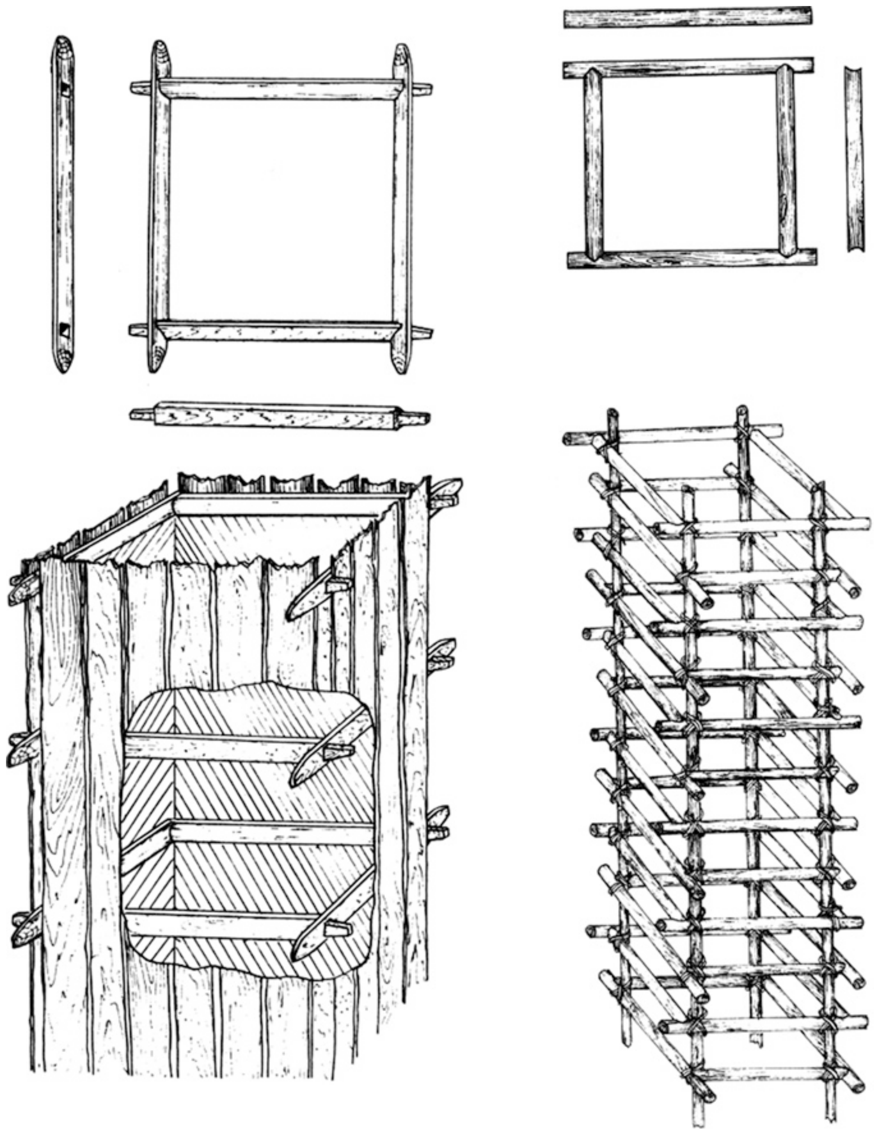


**Fig. 6** The framework of the mine shaft used between Western Zhou Dynasty and the Warring States period, excavated in the remaining site of Tonglvshan mine

drained by having it go through a wood trough into a well and then was delivered out of the well by using a pulley and a pail. In early times, copper ore was taken out of the tunnel by man's pulling it or carrying it on the back. Later, in the Spring and Autumn and Warring States Periods, it was done by using boom and winches.

All the above mentioned indicates that, in the pre-Qin period, the five systems—tunneling, illuminating, water draining, ventilating, and ore delivering—required in mining were already complete thus having ensured a regular operation and provided a foundation for the development mining in later times.

### 3.1.3 Hand Separation and Gravity Separation

Hand separation was low efficient and was usually done by washing the ore with water, getting copper from its ore according to the different weights of copper from that of rock grains in the water. In early times, that was done by first breaking the ore into pieces and then washing them with plates or baskets. In Western Zhou Dynasty, the sluicing device was composed of a bed flow slot, a tail pond, and a water-filtering table. After the ore pieces were washed by water, copper grains were obtained and the tails were drained into the tail pond.

### 3.1.4 Smelting Copper in Shaft Furnace

The shaft furnace used in 1400 BC in Negev, Palestine, was 0.6 m high, and it had to be destroyed before the smelted copper was taken out. The shaft furnace used in Tonglvshan mine in the Spring and Autumn Period was 2 m tall and had a capacity of 0.3 $m^3$. It delivered copper and its residues intermittently, that is, in a so-called semi-continuous operation. The furnace was composed of the base, the hearth, and the shell. A T-shape duct was built in the base to prevent the bottom from freezing, and this structure has continuously been used by later generations. The hearth was built with fire clay, pieces of iron ore, kaolin, and charcoal powder, and its stream-burned stream surface had been mended several times. In the front of the furnace was a feeding door, through which the smelted copper and its residues were taken out. A vent was built on the side of the furnace. (See Figs. 7, 8, 9 and 10)

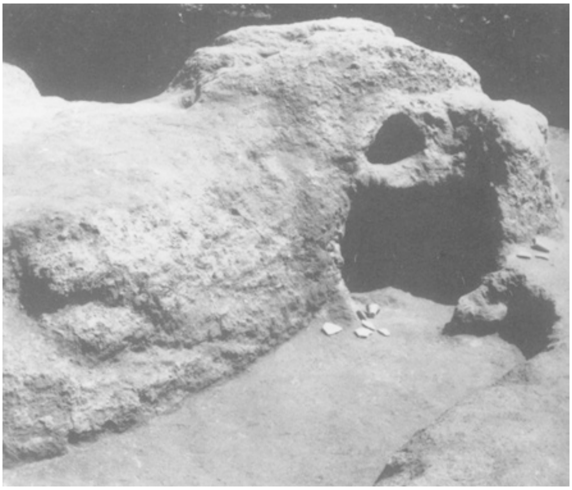
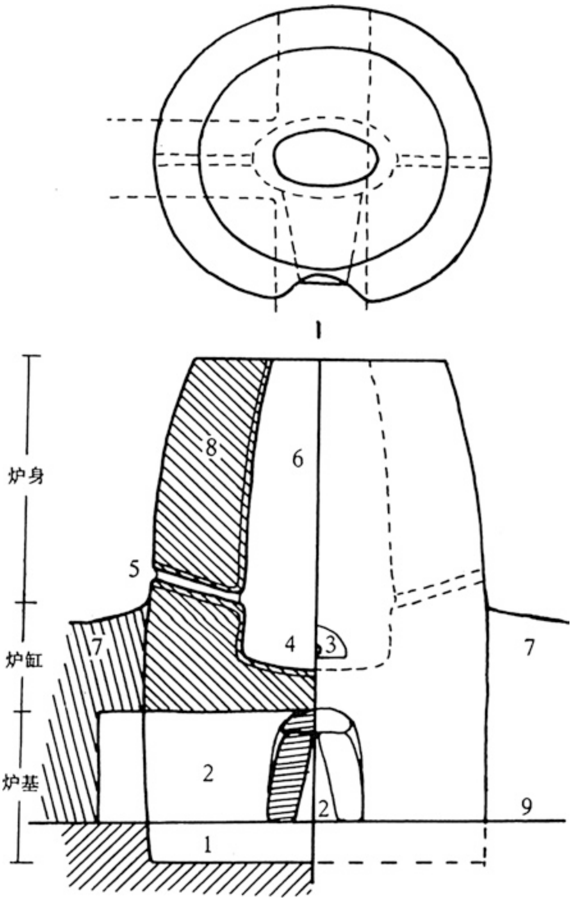


**Fig. 7** A shaft furnace for smelting copper, used during the Spring and Autumn period, excavated in the remaining smelting site of Tonglvshang mine No. 5

**Fig. 8** The retrieved structure of a shaft furnace used for copper smelting. *1* Base; *2* Ventilating slot; *3* Feeding door; *4* Drain hole; *5* Air vent; *6* Inner-wall; *7* Working bench; *8* Outer-wall; and *9* Floor




### 3.1.5 Smelting Copper from Sulfide Ore

In ancient times, there were three kinds of techniques in smelting copper:

1. Oxidized ore deoxidization. By using charcoal as fuel, virgin copper ore and malachite rich in copper oxide, together with iron oxide ore and limestone, were smelted into slag in a black and stream-burned shape. As copper slag separated well, the copper ingot smelted from it contained 94 % copper and 5 % iron. One shaft furnace could produce 30–40 kg copper one time, and 3–4 times per day.
2. To remove sulfide from sulfide ore by dead burning, and then by deoxidization to obtain copper. For example, the copper ingot unearthed from Guichi, Anhui Province, was produced in this way (See Figs. 11 and 12).
3. To smelt mattes from sulfide ore and then to refine the mattes to get raw copper. That was called the technique of sulfide ore-mattes-copper.

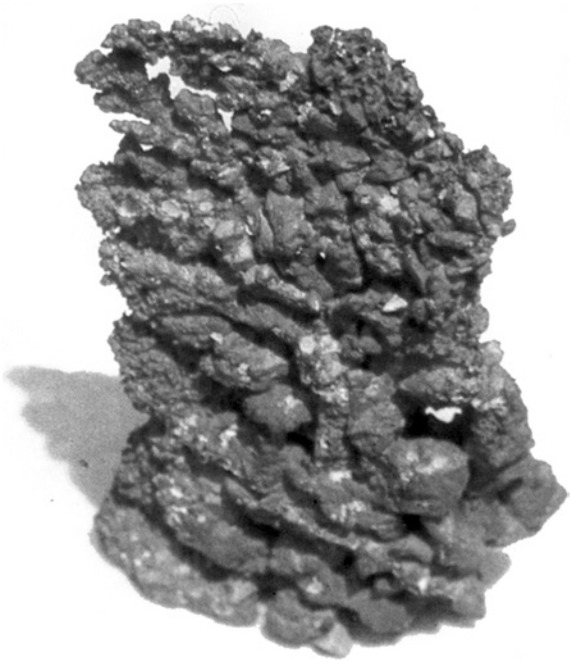


**Fig. 9** Natural copper, taken from the drawing of Tonglvshan mine

**Fig. 10** Peacock stone found in Tonglvshan mine

**Fig. 11** A diamond-shaped bronze ingot produced in Western Zhou Dynasty, excavated in the remaining site of Nanling mine in Anhui Province

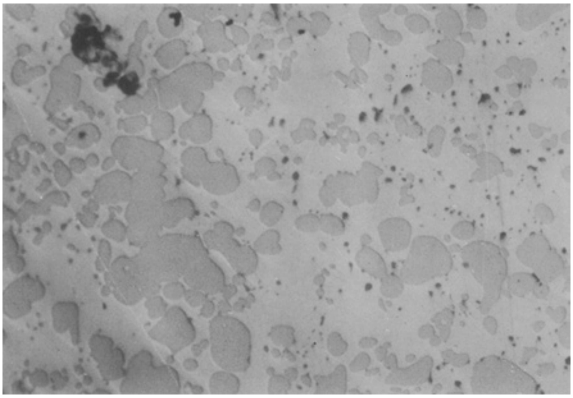


**Fig. 12** The metallographic structure of a bronze ingot produced in Western Zhou Dynasty, excavated at Huijiachong, Guichi, Anhui Province

Native copper deposits were all sulfide deposits. After long-time weathering, they turned into iron on the top and became copper oxide in the second layer, and in the deeper part, they still remained to be sulfide ore. With copper mining expanding, it was necessary to mine sulfide deposits. The availability of copper supply during Shang and Zhou Dynasties owed much to the breakthrough in the technology of getting copper from sulfide ore. Diamond-shaped copper ingot were produced in the areas like Tongling and Fanchang, which must have been refined from mattes slag, because the ratio of copper to sulfide in the slag was less than 4:1. The description in *Ode to Grand Metallurgy* written by Hong Zi in Song Dynasty that "the raw get removed by refining and the essence is collected after re-burning" (See Fig. 13) refers to the use of the sulfide ore-mattes-copper technique. As stated in Miscellaneous Records of the Bean Garden written in Ming Dynasty, the ore needed to be calcined 6 days, and then put into the furnace to be smelted 3 days, which was called "shengpeng" (cook raw). When the ore was ground into pieces, rice paste was added to make it into briquettes from which mattes were to be obtained after 7 days of calcining and 1 day of smelting the briquettes. Then,

之大要不過厥色之有三其爲黃銅也坑有殊名
山多衆樸蜿蟺扶輿鬱積磅礴巀嶭岑崟巖嵬嶢
嶙璘彬閵斑爛瀁璀錯碯脉見函路灼牛飲盤天
井落礦紋異采乍純遽駁燻苗殊性欲斷還絡烏
膠綴金星爍蘞花淡丹砂渥鼠結聚團雜燋散泊
飱餌膏油英潤濯濯宿炎煬而脆解紛剞劂而巧
斵批亢轟博浪之椎陷堅洞混沌之鑿巖雲欲起
而復墜石火不吹而自躍磅磅馳霆剥剥灑雹丘
示掩耳而疾避木客捧心而竦愕膽寒野伏之夔
罔魂褫泥蟠之龍蛾繚乎脩隧黝乎幽壑潛廬旁
呀陰竅斜郤共工觸不周而地維斷神禹闢伊闕

而龍門拓驪山百仞之下穿昆明萬夫之偕作曾
未嬈其功用之博也逮其籠蕢齎畚卓具專諸虎
攫孟賁豕負徒堆阜於平陸矗岑樓於爐步熺炭
周繞蕘薪環附若望而燎若城而炬始束緼於畢
方旋鼓鞴於熛怒鞭火牛而突走騎燭龍而騰驁
戰列缺霹靂於猋庬舞屏翳豐隆於煙霧陽烏奪
耀熒惑遜度石迸髓汋流乳江鑠融膏注鉛再
鍊而麤者消鑠復烹而精者聚排燒而汕溜傾吹
拂而鬆窠露利固孔殼力亦良苦唯彼泉井淘沙
可鑄其浸銅也鉛山興利首鳩僝功推而放諸象
皆取棠辨以易牙之口膽隨味而不同青溢苦以

**Fig. 13** Photocopy of *Dayefu*

copper was to be produced after 8 days of calcining and 3 days of smelting the broken pieces of mattes. The whole process took 27 days with the production of copper going through several stages of refinement. That really shows a long and arduous task to get copper.

The wooden supports used in tunnels, smelting copper in shaft furnaces, and smelting copper from sulfide ore were three inventions in copper mining and smelting in China in Shang and Zhou Dynasties, and they also laid a technological foundation which ensured a continuous copper supply to meet the demands. As stated in Zhouli–Diguansitu that mine owners own land that contains gold, jade, tin, or rock, those in charge of copper mining at that time were all mine owners, and miners were mostly prisoners, slaves, and criminals. As miners were of a humble class, they had to work under very poor conditions and with no guarantee for their safety. Besides, the use of charcoal as fuel entailed cutting a lot of trees, causing a great damage to the ecological system. So, we should say that the technological advancement and civilization in early times were gained at very great costs.

## 3.2 Copper Casting

### 3.2.1 Casting with Stone Molds

The earliest casting molds were made from stone (See Fig. 14). The use of this technique remained in many remote regions of China till Eastern Han Dynasty. In Yunnan, stone molds are still used to cast iron plows.

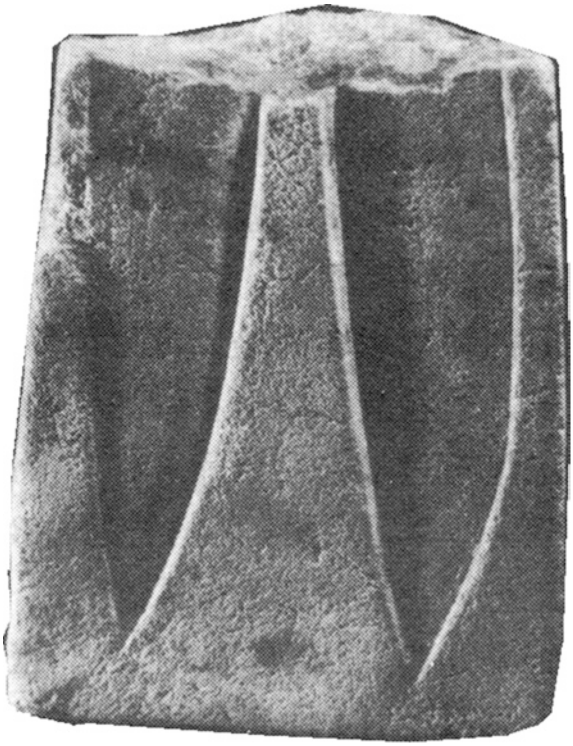


**Fig. 14** A cut stone mold used in the later Shang Dynasty, excavated in Wucheng site at Qingjiang, Jiangxi Province

### 3.2.2 Casting with Complex Pottery Molds

Casting with pottery molds was already the mainstream in casting bronze wares in Xia Dynasty. The capability of casting highly complicated works during the Yin Ruins Period mainly consisted in applying the technique of joining separate castings (See Fig. 15). Take a round Jia, a kind of ancient wine vessel, as an example. The heads of the two columns were first cast. Then, the cast mold was composed of a bottom part, six abdomen parts, three top parts, and four clay cores for the Jia's body and three feet (See Figs. 16 and 17). Casting a You, another kind of ancient wine vessel, was the most difficult job of all. A handle had to be first cast and added to the body of the You, and the cast loop had to be inserted between the cast lid and the cast button before them being combined.

At each of the two ends of the cast loop, there was a hole into which a cast semicircle loop had to be set and combined with the cast handle (See Figs. 18 and 19). Placing a core supporter in the casting mold to ensure the correct position of the mold and the core, and also the desired thickness of the walls was a technique, simple, and efficient, easy to be popularized (See Fig. 20). Separate casting and cast remolding were conducive to specialized labor division, similar to the way

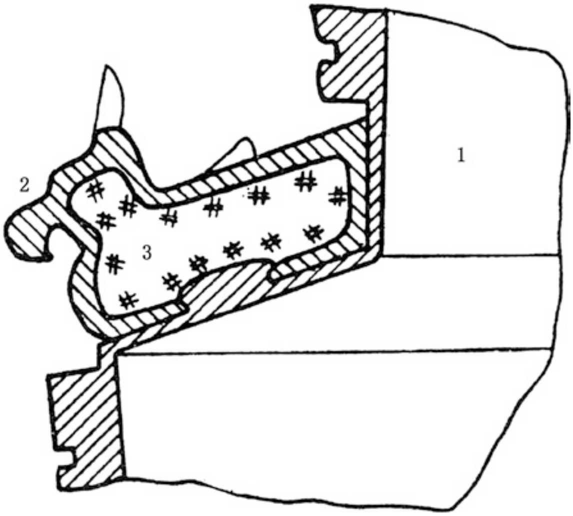



**Fig. 15** A square Lei (an ancient wine vessel) made by joint casting. *1* Body; *2* Attached animal; and *3* Mud core

**Fig. 16** Yaqi Jia (an ancient wine vessel) used in the later Shang Dynasty, excavated in Yin Ruins, Anyang, Henan Province

of production in industrialization (See Figs. 21 and 22), so as to meet the growing demands for bronze wares in society. By the Spring and Autumn and Warring States Periods, cast remolding had been regularly operated in copper casting. And,

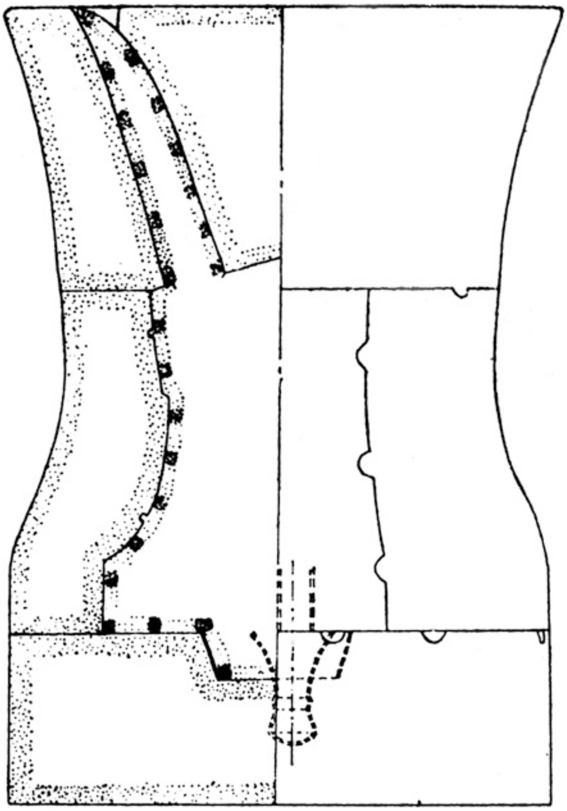


**Fig. 17** Assemble of the casting molds of a Jia

it was a common practice in the Spring and Autumn and Warring States Periods that the cast parts like the ears and the feet of a Ding (an ancient cooking vessel) were connected with the body cast by using the techniques like casting and welding (See Figs. 23 and 24).

### 3.2.3 Casting with Lost Wax Process

Zenghouyi Zun Plate (a kind of wine vessel in ancient times) (See Figs. 25, 26, 27 and 28) unearthed in Suixian County, Hubei Province, is widely recognized as the best one among the bronze treasures of Shang and Zhou Dynasties, whose top ornaments were cast with the lost wax process. The important castings made by way of lost wax in the Spring and Autumn and Warring States Periods also include the bronze ware holder from Zhechuan, Henan Province, Chu Wang Yu (a water container), and hollowed-out coiled lizard pattern ornament found from the tomb of Xugongning (See Figs. 29, 30, 31 and 32). All of these items were

**Fig. 18** A square You, found in a tomb of Shang Dynasty at Dayangzhou, Xingan, Jiangxi Province

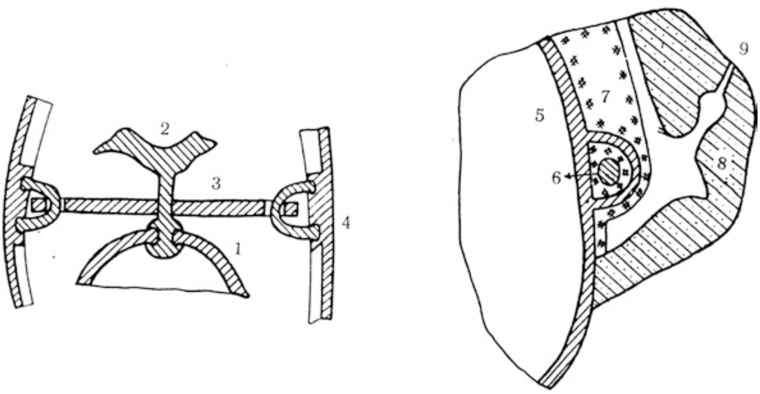



**Fig. 19** A joint cast You. *1* Lid; *2* Lid button; *3* Loop; *4* Handle; *5* Body; *6* Pin; and *7* Mud core of the handle

**Fig. 20** Copper core support at the lower part of the belly of a Ding (pot) produced in Western Zhou Dynasty, excavated in Baoji, Shaanxi Province

**Fig. 21** A pottery mold with an animal head

**Fig. 22** A mold box with an image of an animal's face on the surface of one side, produced during the Spring and Autumn period, excavated in Houma, Shanxi Province

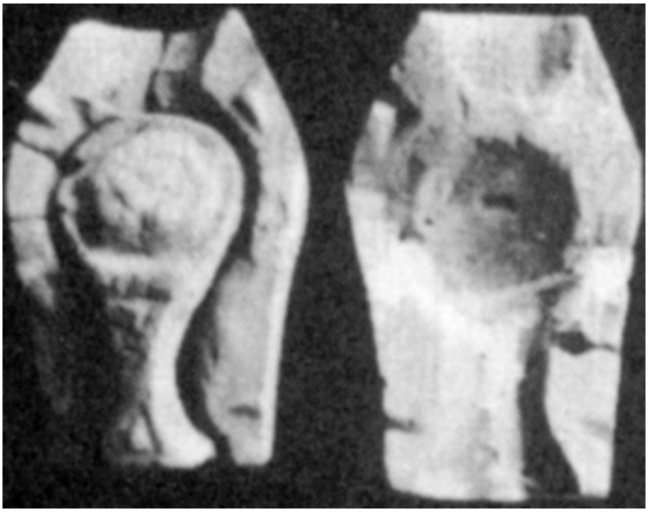


**Fig. 23** Cast mold of a foot of a Ding, produced during the Spring and Autumn period, excavated in Houma, Shanxi Province

proved by experts to have been cast with the technique of lost wax, and some of them have undergone physical and chemical tests and have been restored in their original forms. The use of the lost wax process in China has a long history, and it has never been lost. It might have been invented by Chinese people on their own, because it differs a lot from that in ancient Europe in preparing wax materials and shaping models.

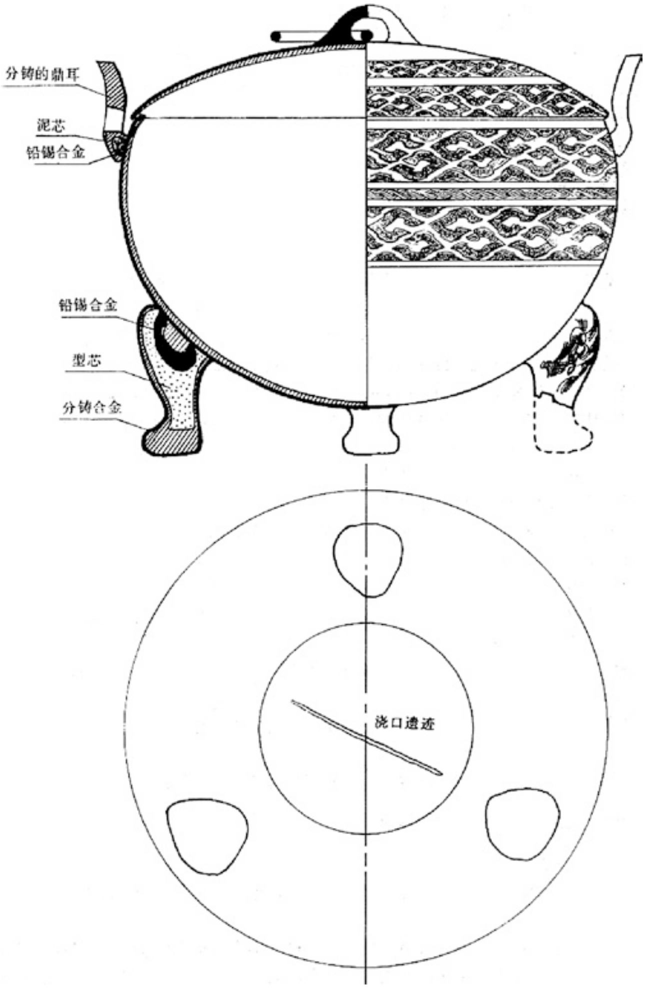



**Fig. 24** A bronze Ding produced in the Warring States period, excavated in Luoding, Guangdong Province

### 3.2.4 Ornamenting Techniques

1. Gold Inlaying. That was to cast an ornament pattern on the surface of the ware and process it into dovetail grooves, and then to inlay gold, silver, or copper wires into the grooves before hammering them flat and polishing them (See Fig. 33). Another way adopted was called "cast inlaying," that is, putting a pre-cast ornament pattern into the casting mold to make the two a joint one.
2. Gold Plating. That was first to clean a ware with acid, and then to cover it with an amalgam of gold and mercury which was to be heated with charcoal. Then,

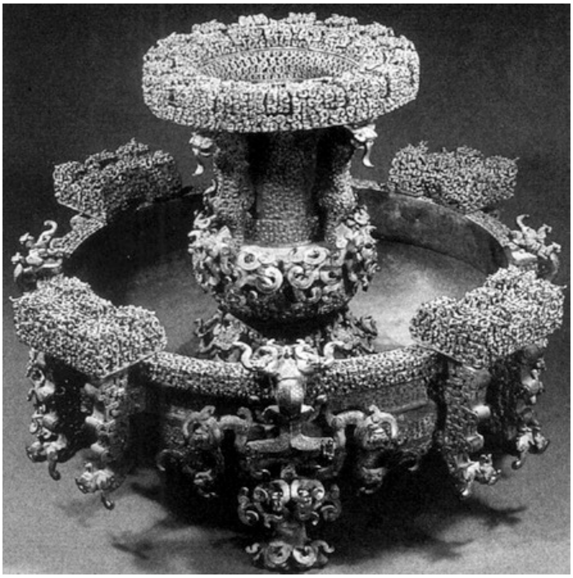
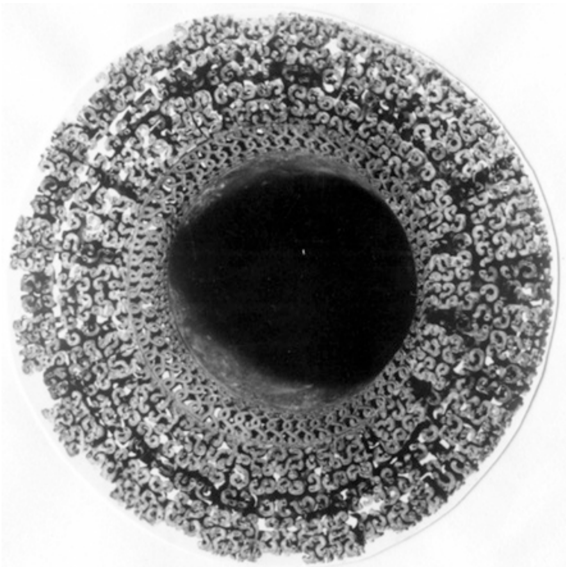


**Fig. 25** A Zun plate found in Zenghouyi's tomb, produced during the Warring States period, excavated in Suixian County, Hubei Province

**Fig. 26** Vertical view of the hollowed ornament on the Zun's neck



after the mercury was evaporated, the gold remained and stuck to the surface of the ware. To ensure the desired result, this process of plating gold could be repeated three to six times (See Fig. 34).

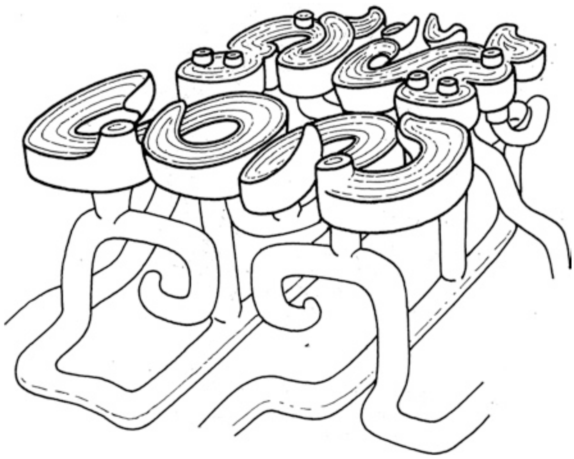


**Fig. 27** Structure of the hollowed ornament on the Zun's neck

**Fig. 28** A bronze Jin (a device on which to put wine vessels) produced in the middle and later Spring and Autumn Period, excavated in Chu cemetery at Xichuan, Henan Province

**Fig. 29** Runner system of the bronze Jin

**Fig. 30** Chu Wang Yu produced in the middle and late Spring and Autumn period, now kept in the Metropolitan Museum of New York

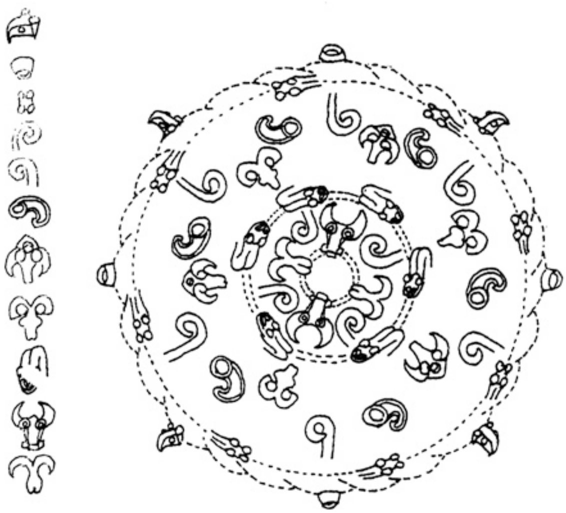


**Fig. 31** 03 knob pattern units and their configuration

## *3.3 The Six Qi (Metal) Rules*

| Qi (metal) usage | Proportioning | Proportion of Bronze and Tin |
|---|---|---|
| Bell and tripod vessel | Tin takes up 1/6 of metal | 85.8 and 14.2 % |
| Axe | Tin takes up 1/5 of metal | 83.3 and 16.7 % |
| Dagger axe and Halberd | Tin takes up 1/4 of metal | 80 and 20 % |
| Blade | Tin takes up 1/3 of metal | 75 and 25 % |
| Knives and Arrows | Tin takes up 2/5 of metal | 71.4 and 28.6 % |
| Copper Mirror | Tin takes up 1/2 of metal | 66.7 and 33.3 % |

**Fig. 32** Bronze ornament with coiled lizard pattern found in Xugongning's tomb

**Fig. 33** A gold-inlaid Dou (an ancient food vessel) produced during the Warring States period, excavated in Changzhi, Shanxi Province

The Six Qi Rules stated in *Kaogongji* (Examination of Workers) shows that people working at casting in the pre-Qin Period already knew the regularities of the change of the mechanical properties of bronze (an alloy of copper and tin)

**Fig. 34** Luanshu Fou (a big bellied and small-mouthed porcelain container) produced during the Warring States period

with the change of the alloy's composition, and they used this knowledge to cast various devices with different properties. By making a practical measurement, we knew that the amount of tin contained in a bronze bell, tripod vessel, and axe, respectively, as is indicated in the Six Qi Rules was quite similar to that contained in the unearthed same objects. But, the tin contained in the unearthed bronze sword and that in the unearthed mirror were different; the former was more than 20 %, and the latter about 25 %.

That difference resulted from the following two facts. One was that, due to the division of states during the Spring and Autumn and Warring States Periods, there were no unified processing specifications. The other was that different workshops adopted different ways of smelting and casting and all of those were more reasonable than that stated in the Six Qi Rules. In Henan, Sichuan, Guangzhou, and other places were found bronze paper knives which all contained 28–32 % tin. Some of the knives were quenched in order to make them tougher and more tensile. This kind of bronze and tin alloy has never been used in modern industry thus needing further research. We should say the practice in smelting and casting in the pre-Qin Period was widespread and deep-going, and therefore, it cannot be underestimated.

### 3.4 Stages of the Bronze Age with Their Technical Properties and Representative Products

1. The Stage of Emergence—from the later Neo-stone Age to the beginning of Xia Dynasty. In the south of Shanxi, the west of Henan, the Liaohe River basin, the east of Shandong, Gansu, and Qinghai were found some small bronze devices which had been forged or cast in this stage (See Fig. 35).
2. The Stage of Growth—from the later Xia Dynasty to the middle of Shang Dynasty. In the remaining site at Erlitou, Yanshi, Henan Province, we excavated some Jue and Jia (both were ancient wine vessels) (See Figs. 36 and 37) produced in that stage, which constituted the set of ritual devices in early times. The ornament of TaoTie (a mythical ferocious animal) pattern on them was fine and gorgeous, rich in cultural connotations. In its molding, material were added plant ash, old molds, and other poor materials, thus having reduced its shrinkage rate, improved its casting quality, and enabled the use of composite castings. That was a great breakthrough in pottery-mold casting, and a significant milestone in the history of casting in China. The big square Ding found in Shangcheng, Zhengzhou, which had been produced by joining several separately

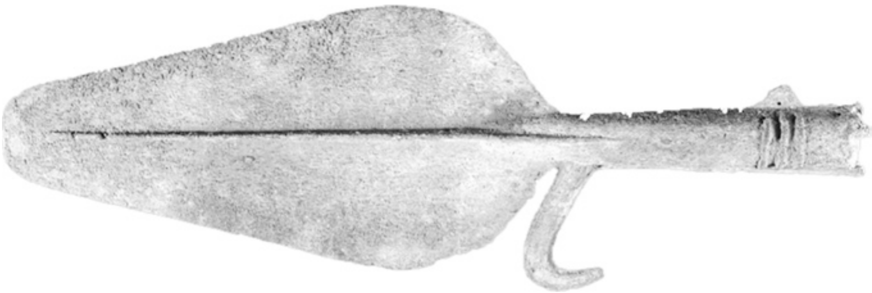


**Fig. 35** A bronze spear used in 2000 BC, found at Qijiaping, Guanghe, Gansu Province

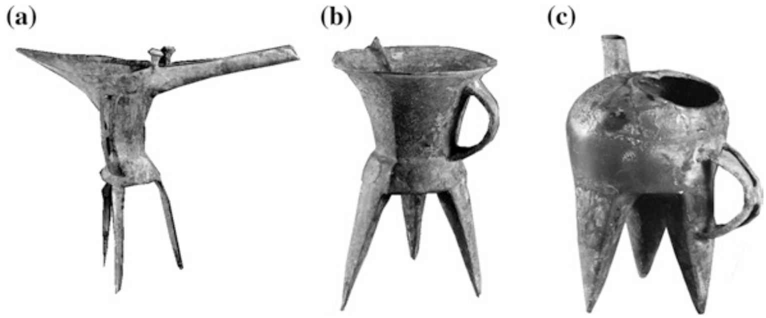



**Fig. 36** A set of ritual devices used in Xia Dynasty, excavated in Yanshi, Henan Province. **a** Jue. **b** Jia. **c** He (all the three were ancient wine vessels)

**Fig. 37** A bronze bell produced in Xia Dynasty, excavated in Yanshi, Henan Province

cast parts together, shows that during the stage of growth, though the casting techniques had been greatly improved, the smelting furnaces and the cast mold were still inadequate so that joining separate cast parts had to be adopted to produce big-size cast devices. In the remaining sites used in Shang Dynasty at Panlongcheng, Huangpi district of Wuhan, and at Wucheng, Qingjiang, Jiangxi Province were also found many bronze ritual devices and daily used articles, which indicate that in that stage the smelting and casting industry proceeded on a much greater scope than before.

3. The Stage of Prosperity—from the later Shang Dynasty to the beginning of Zhou Dynasty. In Yin Ruins and Zhouyuan, there are remnant casting sites as large as ten thousand to one hundred thousand square meters. There the bronze ritual devices, musical instruments, military weapons, vehicles, and the articles for daily use produced during the stage of prosperity were complicated in shape and pattern design, thus unique among the world bronze cultures (See Figs. 38 and 39). The bronze devices found at Sanxingdui, Guanghan, are unique in shape, for example, the one like a human head with two much-protruding eyes and two unusually large ears, which perhaps imply the sharp ears and bright eyes that are typical of the appearance of a goddess of wisdom (See Fig. 40).
4. The Stage of Expansion—from the middle of Western Zhou Dynasty to the early Spring and Autumn and Warring States Periods. The ritual music system developed in Western Zhou Dynasty and continued till the Spring and Autumn and Warring States Periods. During that period of time, the industry of bronze smelting and casting in various states had an enormous expansion and led to a great increase in the production of bronze devices. That was compounded with the innovated casting techniques including core supporting, mode making, and separate castings joining. So far, no important bronze devices used

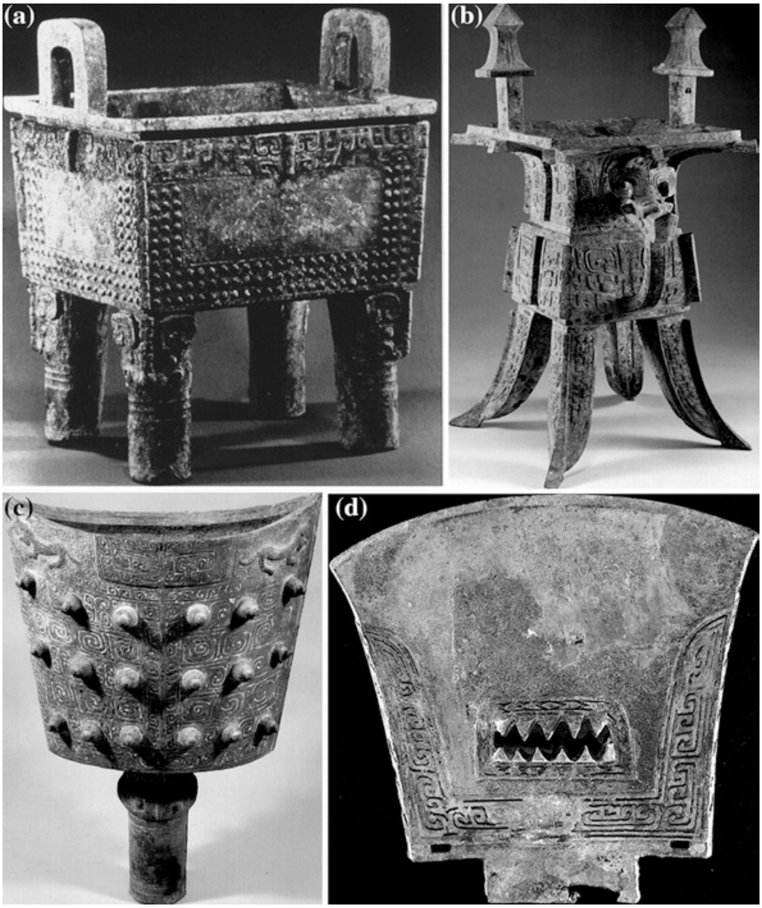



**Fig. 38** Bronze devices produced in Shang Dynasty. **a** Simuxin square Ding. **b** Square Jia. **c** Bronze Nao (a musical drumming instrument). **d** Bronze Yue (an ancient weapon)

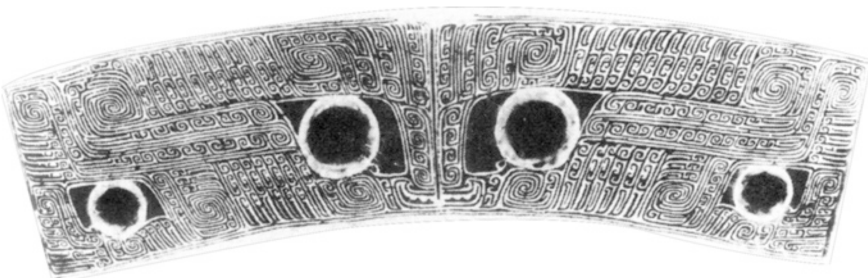


**Fig. 39** Ornament patterns on bronze devices in the later Shang Dynasty

**Fig. 40** A gild bronze head produced in Shang Dynasty, excavated in Guanghan, Sichuan Province

in the imperial courts in Zhou Dynasty have been excavated, but in the cemetery of Guo State and the tomb of Zenghouyi have been found sets of Ding and Gui (cooking and food vessels). It is said that the imperial court had the rule of using eight Guis and nine Dings, but there is another belief that it was twelve Dings rather than eight. Each of the bronze devices produced in Western Zhou Dynasty has a lengthy inscription which covers many things including territory granting, benefit bestowing, military merits, land systems, etc. (See Figs. 41, 42, 43, 44 and 45), serving as precious data for studying Western Zhou Dynasty in social, economic, political, military, and cultural aspects.

**Fig. 41** A round Ding produced in Western Zhou Dynasty, excavated in Chunhua, Shaanxi Province

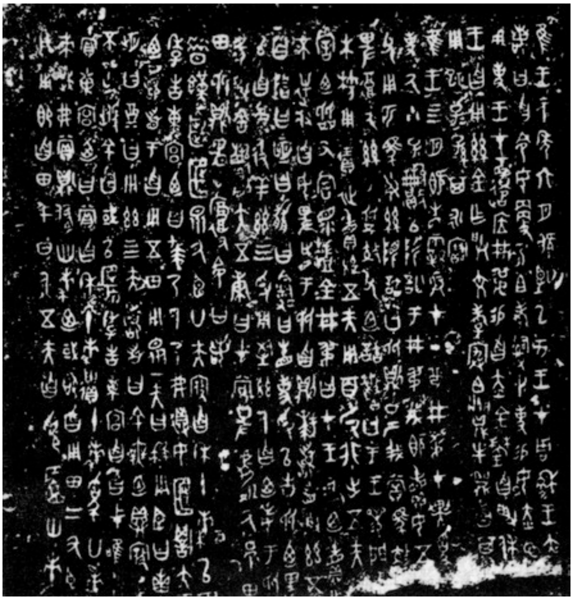
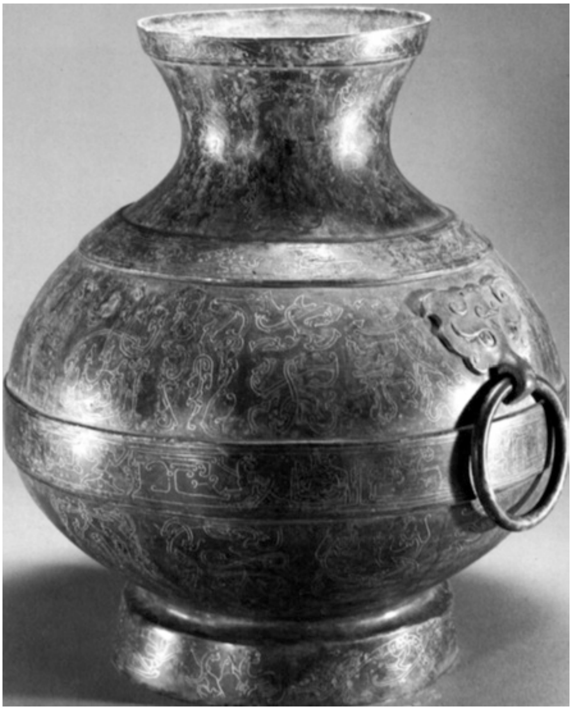


**Fig. 42** A Ding's inscription rubbing which tells that the value of five slaves was the same as that of a horse and a bundle of silk cloth (according the textual research conducted by Guo Moruo)

**Fig. 43** Jinhousu bronze chimes produced in Western Zhou Dynasty

**Fig. 44** A bronze Ding with clouds patterns, produced during the Spring and Autumn period



5. The Stage of Transformation—from the later Spring and Autumn Period to the Warring States Period. This stage was characterized by the significant technical transformation from adopting mode casting only to the mixed use of a new series of metallurgical techniques about casting like whole casting, separate casting, cast joining, lost wax process, cast welding, gold inlaying, gold plating, and engraving.

**Fig. 45** Bronze instruments. **a** Sickle. **b** Shen. **c** Lai. **d** Knife. **e** Chisel. **f** Axe

The representative products of that time include the square table on a dragon-phoenix pattern base excavated in Zhongshanwang's tomb at Pingshan, Hebei Province (See Fig. 46), Chenzhang kettle found at Xuyi, Jiangsu Province, as well as many others. Among those products, the big-sized chimes found in Zenghouyi's tomb are considered the most representative of castings as to their artistic and scientific levels during the Warring States Period (See Fig. 47). The chimes made from bronze show that, in the early Warring States Period, the 7-tone scale in music was already used, which enabled tone modulation and tone change. The chimes' double-tone mechanism was guaranteed by their unique structure, exquisite foundry technique and skilled workmanship of tone modulation. They were all cast with pottery molds, which indicated the top of that technique (See Fig. 48). As to the chemical composition of each bell of the chimes, copper takes up a portion of about 85 %, tin about 14 %, and lead about 1 %. That is an optimal alloy composition for a bronze musical instrument.

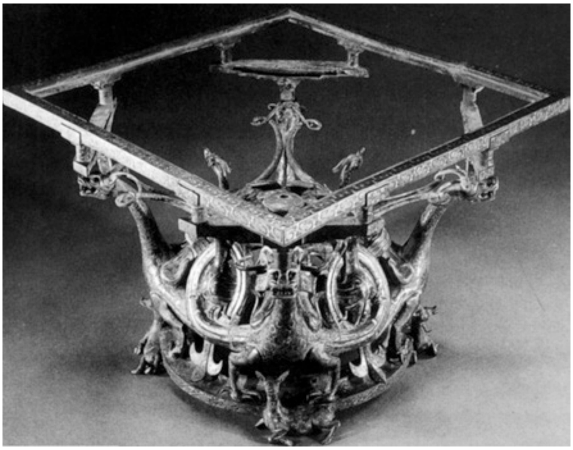


**Fig. 46** A square table on a base of gold-inlaid dragon and phoenix pattern, produced in the Warring States Period, excavated in Zhongshanwang's tomb, at Pingshan, Hebei Province

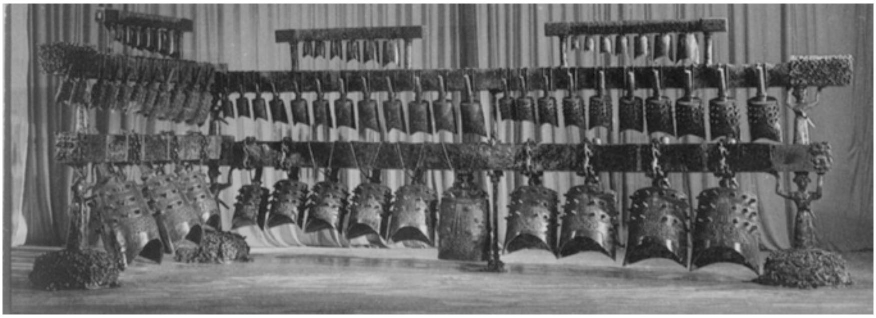


**Fig. 47** The big chimes found in Zenghouyi's tomb

The sword used by Lord Yue Goujian was the representative of swords made from bronze (See Fig. 49). As one of a complex type (See Fig. 50), the sword contains more tin in its edge than in its ridge, thus having both properties of toughness and gentleness. It was shaped excellently, having an arc edge and a blood slot on it. Its top part was ornamented with several circles having a common center, with each having a wall of only 1 mm thick. Its casting molds were made by being scraped (See Figs. 51 and 52). The sword's body was ornamented with diamond patterns which were shaped by coating the surface with a sticky high tin alloy so as to form a microlite protective covering, and the parts which were not coated with the sticky alloy had been touched so much that the patterns on them became almost flat. Considering the appearance, the material made from, the shape, the workmanship and the ornaments, Lord Yue Goujian's sword and Lord Wu Fuchai's sword were both outstanding ones, hence they enjoyed a reputation of being the world's best. It had been a custom for one to carry a sword all day long in the states of Wu and Yue, which was later followed by people in other states.

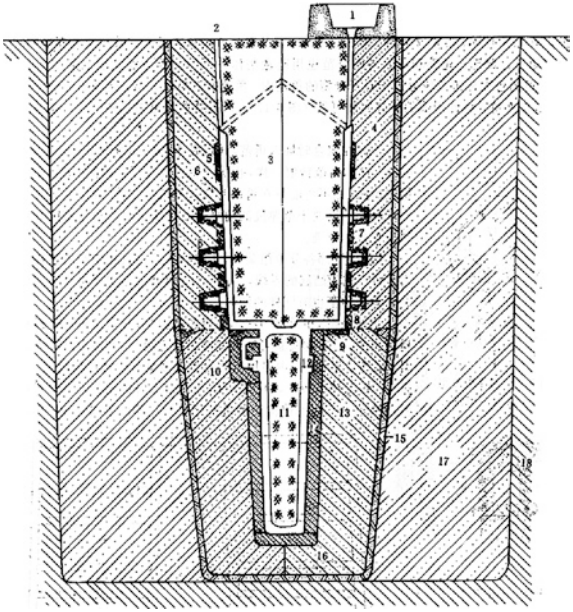



**Fig. 48** The cast mold of a Yong bell

## *3.5 Metallurgical Technique Traditions About Casting and Their Impacts*

1. In classical works, "making pottery" and "smelting metals" or "molding pottery" and "casting metals" are always mentioned together. To some extent, that refers to the fact that bronze smelting and casting originated from pottery making, and in our ancestors' mind, smelting and casting were closely associated with pottery molding.
2. In *Shuowenjiezi* (Origin of Chinese Characters), casting was called "daye" (bigger making) and forging "xiaoye" (smaller making), which reflects the difference positions of casting and forging in our ancestors' mind. The traditional metallurgical techniques about casting in ancient China differed a great deal from the traditional metallurgical techniques about forging in ancient Europe, which exerted a significant influence on later generations.
3. There have been many Chinese concepts and idioms derived from smelting and casting. In *Zhuangzi–Xiaoyaoyou*, there are words like "taking Nature as a big furnace, and taking Creation as smelting and casting things." That is to say, in our ancestors' mind, the universe resembled a big furnace, in which everything in nature had been created by being smelted and cast. In *Shiqiangpan Zhuming*, there are words "Jing Shi Yu Hui," among which Jing refers to shape or mold, meaning one should set an example or act as a model for other people. "Wei Shi Rong Fan" in *Chenshu–Gaozu Benji* conveys the similar meaning. The Chinese phrases of "mofan" (model), "fanwei" (scope), "fanchou" (category),

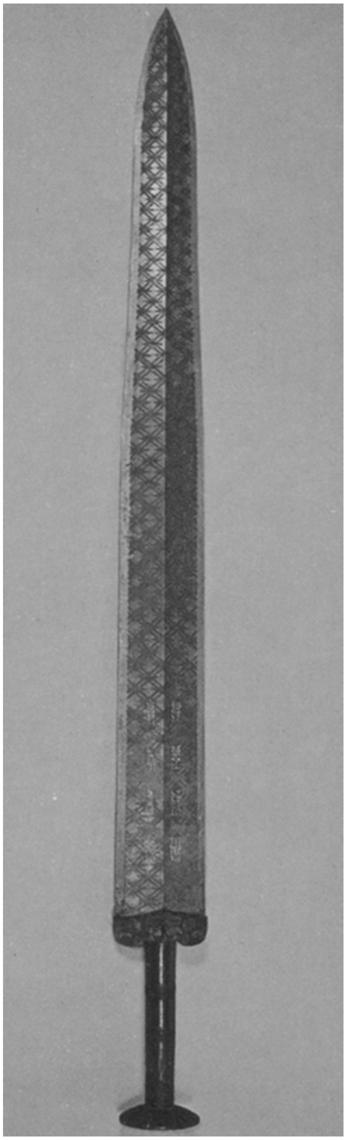


**Fig. 49** Lord Yue Goujian's sword produced during the Spring and Autumn period, excavated in Jiangling, Hubei Province

"guimo" (scale), "kaimo" (model/example), "guifan" (norm), and "mohu" (unclearness) were all terms originally used in the smelting and casting industry, and later were more generalized in meaning. The Chinese character "xiao" (to sell) originally meant "rongrong" (to smelt and merge) and then has carried the meaning like "huaxiao" (cost or spending), "xingxiao" (to sell), and "xiaoshou" (to sell). The characters "xue wei ren shi, xing wei shi fan" (Being a teacher, one should act as a model for his students) written by Mr. Qigong, a

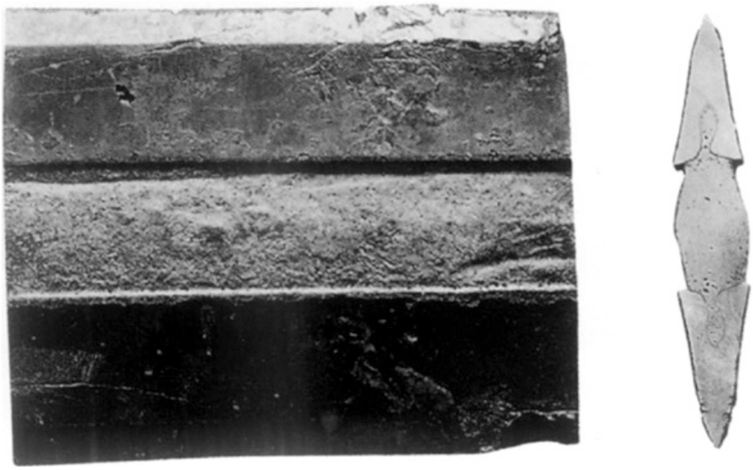


**Fig. 50** The section of a complex sword

**Fig. 51** A drawing of several circles with a common center on the sword's top

distinguished Chinese calligrapher, for Beijing Teachers' University to use as the school motto were just the extension of those concepts and idioms.

4. There is a Chinese idiom "ke shao ji qiu" (meaning children carry on their fathers' lifework). The character "ji" refers to an arrow container and the character "qiu" means skin bag (part of a blowing device for a blast furnace), according to the description in *Liji–Xueji* that children born in a family good

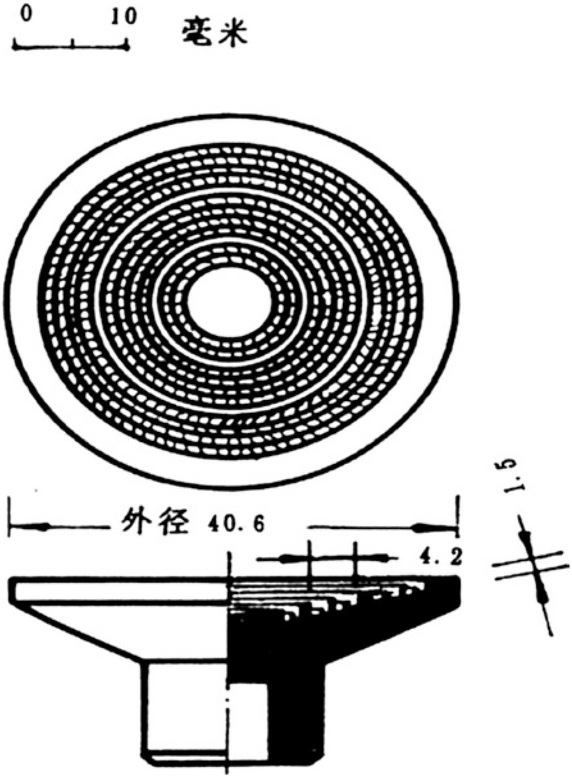



**Fig. 52** The section of several circles with a common center on the sword's top

at shooting arrows must learn ji, the techniques about arrow shooting, and the children born from a family good at smelting and casting metals must learn qiu, the techniques about smelting and casting ("Liang gong zhi zi bi xue wei ji, liang ye zhi zi bi xue wei qiu"). It is wrong to say that ji refers to a winnowing basket, and qiu refers to fur clothing, which used to be a belief held by some people. In the pre-Qin Period, craftsmen, artisans, or technicians tended to live together in tribes and their skills or techniques were carried on by their children who had started to learn their fathers' expertise at an early age and then they became experts themselves as if they were born talents in their fathers' fields. That was the tradition of the Chinese handicraft industry in early times, which had both merits and demerits.

5. In ancient China, there was a Five Element Theory. In *Guoyu–Zhengyu*, it is stated that earth, metal, wood, water, and fire constitute everything in nature. *Book of Documents-Great Plan* described metal as "supple and easily changeable in shape." Babylonians and Egyptians believed that water, air, and earth are three essential elements constituting all in the universe while Greeks considered fire should be added to the three. Only the Chinese ancestors regarded metal as an indispensable element, which, together with water, fire, wood, and earth, help create all the things in the universe.

### 3.6 Casting Money, Mirrors, Images, and Bells

1. Money casting. Money was cast by using copper molds, like the molds used for casting Yibiqian in the state of Chu during the Spring and Autumn and Warring States Periods (See Fig. 53). In Western Han Dynasty, copper money was produced by casting one side with copper molds, and casting the other with pottery molds (See Figs. 54 and 55). Casting money by *die* (set) was prevalent during Southern and Northern Dynasties. One money mold had 6 qian, and one *die* was 12 molds. So, to cast one *die* was to cast 72 qian (See Figs. 56 and 57). Multiple casting molds included those of one side and also those of two sides, similar to those used in the modern multiple-molding. That technique remained to be used in the 1980s in Guangzhou and Foshan, for casting some small devices like sewing machine parts and locks. Casting money of standard

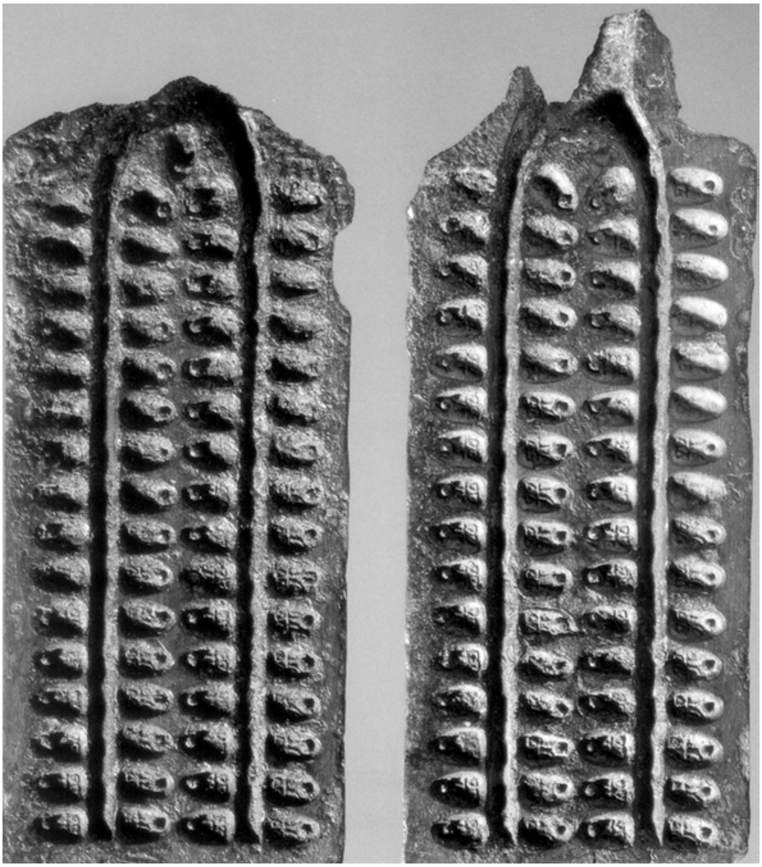


**Fig. 53** Copper molds for casting Yibiqian, used in the Warring States period, excavated in Zhengji, Fanchang, Anhui Province

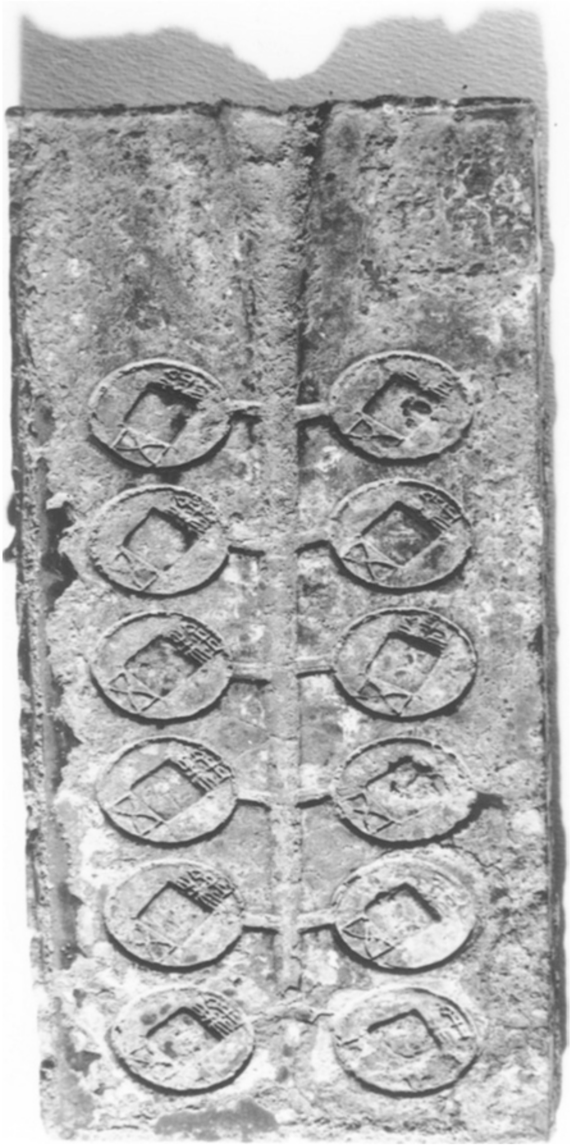


**Fig. 54** Copper molds for casting Wuzhuqian, used in Western Han Dynasty, excavated in Xi'an

value was popular during Tang and Song Dynasties and that money was cast by using wet sand molds. Since that kind of molds was not easy to keep in shape, no remnants of the kind have so far been found (See Fig. 57).

2. Mystery of the Translucent Mirror. By using laser to examine the surface of the mirror (See Fig. 58), we know that the so-called translucence effect was caused by the undulation on the surface of the mirror which had resulted from the casting's residual stress and surface grinding.

**Fig. 55** Copper molds for Daquan Wushiqian, used in Han Dynasty, now kept in the Chinese National Museum

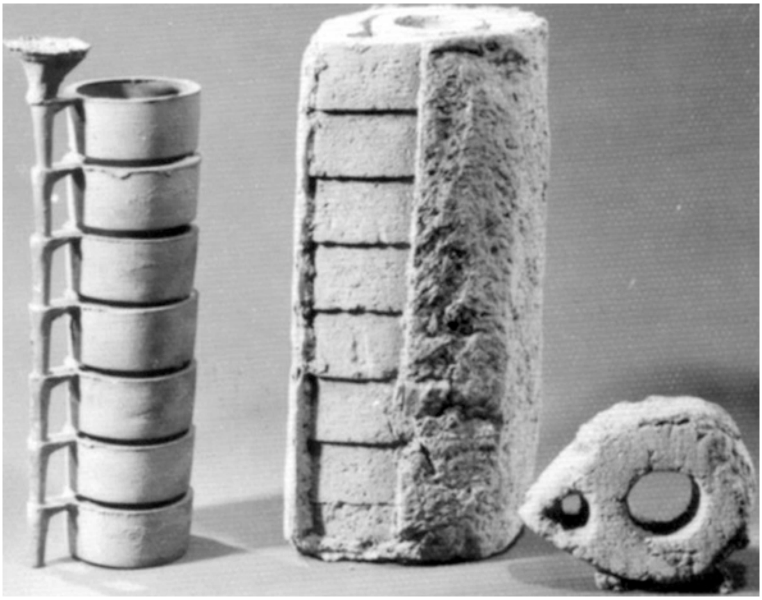


**Fig. 56** Cast molds for Die, used in Eastern Han Dynasty, excavated in Wenxian, Henan Province

3. Zhending Buddha. As stated in a proverb that Changzhou has a stone lion, Dingzhou has a brick-wooden tower, and Zhendingfu has a big Buddha, the three things are great treasures in Hebei Province. According to the inscription

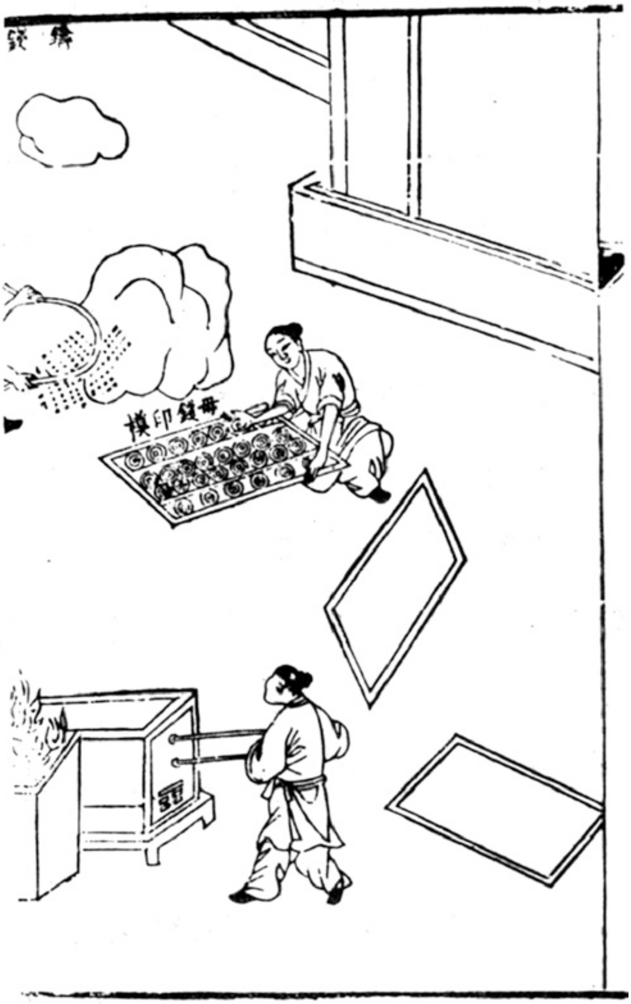



**Fig. 57** A drawing of the process of casting money, taken from *Tiangong Kaiwu* (The Exploitation of the Works of Nature)

on the stone tablet attached to it, the bronze Buddha, which is 22 m high and weighs 36 ton, and first set up in the sixth year of Kaihuang, Sui Dynasty (586 AD), and then rebuilt in the fourth year of Kaibao, Song Dynasty (971 AD), was cast by stacking 7 mud molds, and 6 processed iron pillars were erected in its base which was then filled with raw iron (See Fig. 59).

4. Yongle Bell. The well-known bell, which is 6.75 m high, 3.3 m in diameter, and 46.5 tons in weight and has a scripture of 220,000 words inscribed on its body, was cast during the Yongle period (1418–1422 AD) with 7 mud molds stacked together (See Fig 60). It is famous around hundred Li with contents of tin 16.4 % and lead 1.1 %.

**Fig. 58** A translucent mirror produced in Western Han Dynasty, now kept in Shanghai Museum

## *3.7 Copper–Nickel Alloy and Brass*

1. Copper–nickel alloy and copper–arsenic alloy. In *Annals of Huayang Kingdom* written by Chang Qu in Eastern Jin Dynasty, it is stated that Tanglang County produces silver, lead, cupronickel, and mixed minerals. In the eighteenth century, copper–nickel was introduced into Europe as Chinese silver, and in 1823, Britain and Germany successfully learned to produce it and put it into wide use in industry. In ancient China, copper–nickel was an alloy of copper and nickel. But in Chunzhujiwen written in Northern Song Dynasty, the same name was given to an alloy that was produced by putting a mixture of Arsenic (As2S2) and jujube flesh into a copper liquid and then adding Glauber's salt (Na2SO4) into it to get the residues.
2. Zinc and Brass. The difficulty in getting zinc from its ore is that because of the little difference between its boiling point (907 °C) and its restoring point (904 °C), cooling devices must be used to retrieve zinc. In this respect, China differed from India in ancient times. India adopted a way of down-cooling, that was, by using a distilling tank with a long and thin neck penetrating the partition and extending to the below for cooling zinc. China adopted a way of up-cooling by using a dipper in the distilling tank to cool the zinc vapor. The fact that a lot of money was cast with brass during the Jiajing Period in Ming Dynasty indicated that the production of zinc had been on a large scale at that time and it was mainly a practice in provinces like Guangxi, Guizhou, and Yunnan.

**Fig. 59** A bronze Buddha produced in Northern Song Dynasty, now kept in Longxing Temple, Zhengding, Hebei Province

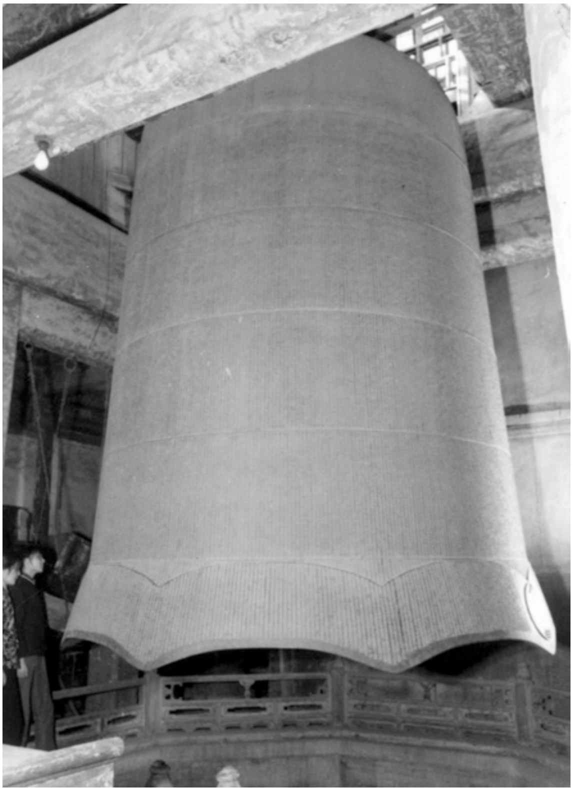


**Fig. 60** Yongle Bell cast during the Yongle period in Ming Dynasty, now kept in Dazhong Temple, Beijing

## *3.8 Copper Forging*

1. Sisa, a term used in ancient China for copper forging. Red copper was often used as raw material. After being hammered and welded into a certain shape, the red copper would become thin and light and could be used to make the image of a human being, a turtle, or a crane of several meters tall. The well-known places rich in red copper included Yixian, Changdu, etc.
2. Bell bronze forging. The bronze containing 20 % tin was called bell metal used to cast bells, gongs, and cymbals. The traditional way of forging gongs and cymbals is still adopted in Changzi, Shanxi Province, and Wuhan, Hubei Province. It is to use the bronze ingot containing about 23 % tin, and, at a temperature between 500 and 700 °C, forge it with its metal structure being at a phase of $\alpha + \beta$ or $\alpha + \gamma$. If the temperature is below 520 °C and its metal structure is at a phase of $\alpha + \delta$, the bronze ingot cannot be forged. When the ingot is heated to 700 °C, it is quenched with water, and at this time, its crystal grains are distributed in $\beta$, the martensitic grain boundary. In this way, the mechanical properties of the bronze could greatly be improved so as to be easily shaped and tuned in tone (See Fig. 61).

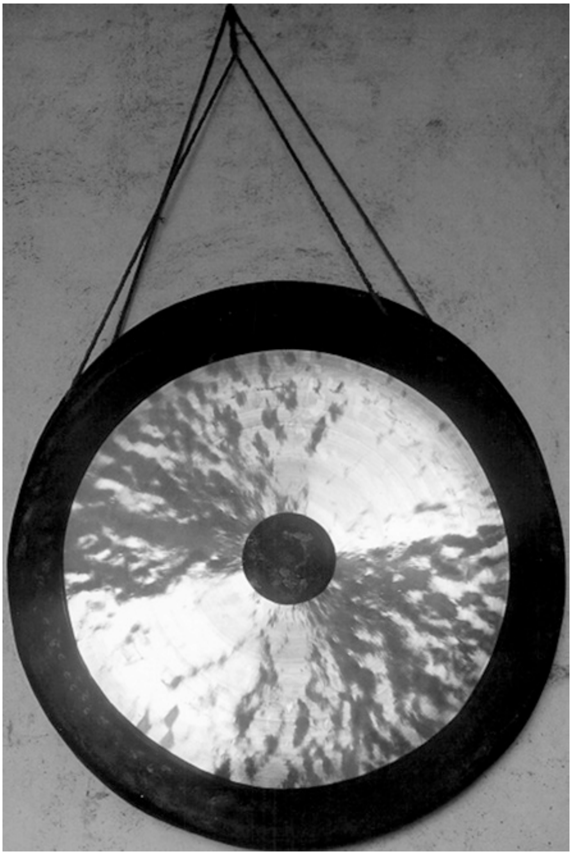


**Fig. 61** A gong used to clear the way when beaten, 1 m in diameter, forged at Jiuxinglu Workshop in Changzi County, Shanxi Province

# 4 Lecture 2 Iron Metallurgy

## *4.1 Stages of Iron Age*

### 4.1.1 Stage of Processing and Using Meteoric Iron Devices—Shang Dynasty

In Gaocheng, Hebei Province, Pinggu, Beijing, and Junxian, Henan Province were excavated some Shang Dynasty bronze battle axes (called Yue in Chinese) with meteoric iron blades containing 6–10 % nickel (See Fig. 62), which indicated that meteoric iron was used in bronze smelting and casting and such use perhaps promoted the invention of the techniques for iron smelting and casting. In the description in Yizhoushu that the enemies were slayed with yellow Yue and black Yue, the mentioned black Yue must have referred to the bronze tomahawk with meteoric iron blades. There are also descriptions in some classical works about meteorite dropping from the sky. *Book On The Southwest Outlying District* written by

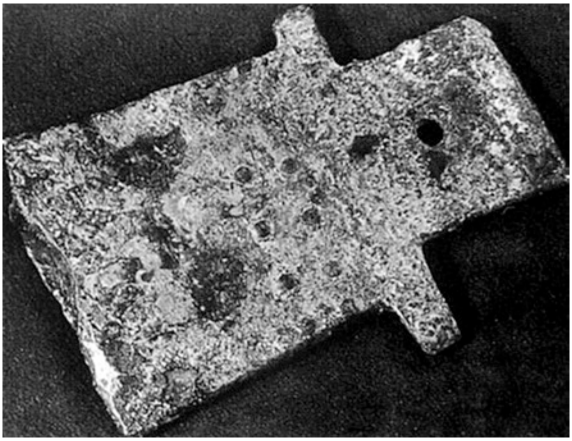


**Fig. 62** A bronze tomahawk with meteoric iron blades made in the late Shang Dynasty, excavated in Gaocheng, Hebei Province

Fan Chuo in Tang Dynasty, says that Nanzhaowang has a sharp sheath dropped from the sky. And *Miscellaneous Morsels of Youyang*, written by Duan Chengshi in Tang Dynasty, mentions a spear-like weapon with a poisonous point which had been dropped from the sky into the earth several meters deep and then was obtained by someone by digging the earth after his worship of the spot.

### 4.1.2 Stage of Producing not Purely Iron Devices—between Western Zhou Dynasty and Western Han Dynasty

Although iron devices were already used in the later Western Zhou Dynasty and the Iron Age began in the Warring States Period and continued in Western Han Dynasty, weapons used during that period were cast with much more bronze than iron because of the deficient techniques in iron and steel making (See Figs. 63 and 64).

**Fig. 63** An iron sword with a jade handle, produced in Western Zhou Dynasty

**Fig. 64** An iron pickaxe (called Jue) produced in the Warring States Period, excavated in Gaocheng, Hebei Province

**Fig. 65** An iron Cha (spade), produced in Eastern Han Dynasty

### 4.1.3 Stage of Producing Purely Iron Devices—from Eastern Han Dynasty till Qing Dynasty

The expansion of iron- and steel-making technology, especially, the unique techniques in producing hot-metal carburized steel, in the later Eastern Han Dynasty through Southern and Northern Dynasties played a key role in promoting the production and the widespread use of purely iron devices (See Figs. 65, 66, 67, 68, 69 and 70). The iron ox excavated at Pujindu, Yongji, Shanxi Province, which had been used to hold the floating bridge at Pujindu, was cast in the year of 724 AD (the twelfth year of Kaiyuan in Tang Dynasty). As described in *Songshi–Fangji Zhuan*, there were eight iron oxen setup to hold the floating bridge in the river, with each ox weighing dozens of tons. In 1988, the four iron oxen and four iron men on the eastern bank were excavated. Each of the oxen was 3.3 m long, 2.5 m tall, and 18 tons heavy and under its belly stood 3 three-meter-long iron stakes (See Figs. 71 and 72).

## *4.2 A Major Chinese Invention—Pig Iron Metallurgy*

### 4.2.1 Solid Iron Reduction at Low Temperature and Liquid Iron Reduction at High Temperature

In the early times, people in the Western Asia and Europe smelted iron in a block furnace at low temperature to get sponge iron, which was then to be heated and forged into wrought iron after removing the residues (See Fig. 73). By contrast, the Chinese ancestors smelted iron in a shaft furnace at high temperature to get liquid pig iron (See Fig. 74). This invention of great originality has laid the foundation for China to have ranked among the first rate of the world in iron and steel technology.

**Fig. 66** An iron pickaxe (called Jue), produced in Eastern Han Dynasty, excavated in Nanyang, Henan Province

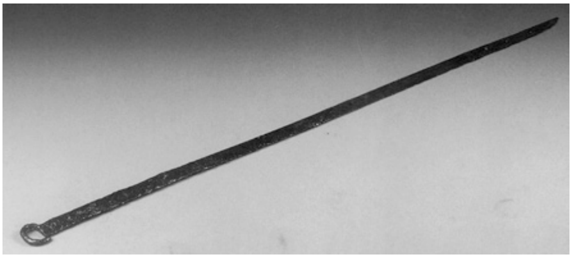


**Fig. 67** A gold-inlaid iron sword, made in the 6th year of Yongchu, Eastern Han Dynasty, excavated in Cangshan, Shandong Province

### 4.2.2 Reasons for the Early Invention of Pig Iron Metallurgy in China

In China, iron smelting and casting came from copper smelting and casting. The traditional metallurgical techniques centering on copper casting and the corresponding processes had been passed from generation to generation, thus leading to a natural emergence of pig iron metallurgical techniques. In Roman times in Europe, pig iron was occasionally obtained due to the accidentally higher temperature inside the furnace, yet it was broken once it was forged and therefore had to

**Fig. 68** Iron plowshares and grinder

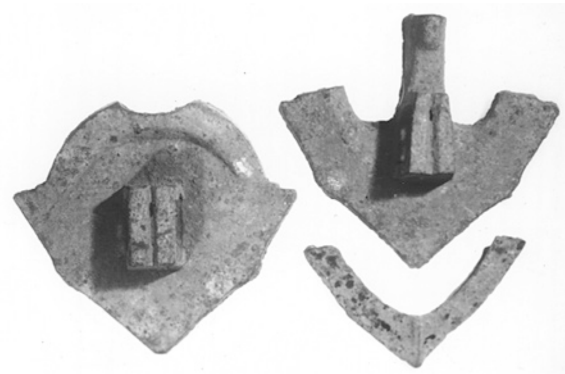


**Fig. 69** Molds for casting iron plowshares

be abandoned as it was useless. In China, as cast forming was adopted, even if pig iron was fragile, it could still be cast into devices of certain shapes through a process of softening. So, as far as using iron and steel technology in ancient times was concerned, a Western worker was just a blacksmith, while a Chinese worker was an expert at casting.

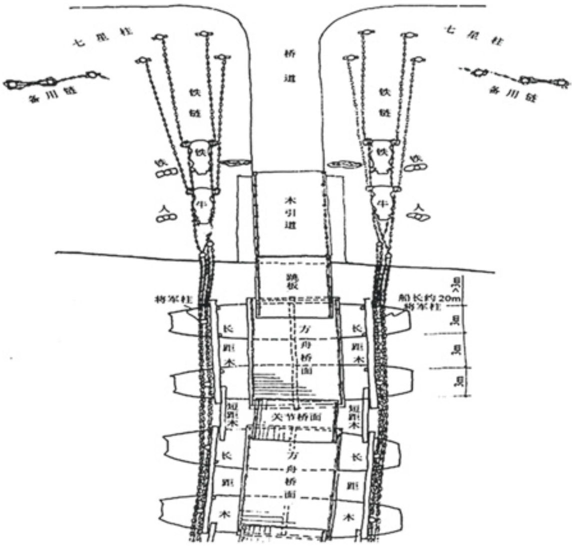
## *4.3 Iron and Steel Technology-based Pig Iron Metallurgy in Ancient China*

### 4.3.1 Pig Iron Smelting

The shaft furnaces used in the Warring States Period for producing pig iron resembled those for producing bronze. In Han Dynasty, a kind of large-sized oval-shaped furnace was used, with its hearth 2.7 m long and 5–6 m high, having a

**Fig. 70** An iron plowshare mold used in Tang Dynasty, excavated in Xi'an

**Fig. 71** The structure of the floating bridge at Pujindu




Plan of the restored floating bridge at Pujindu over the Yellow River in the Tang Dynasty

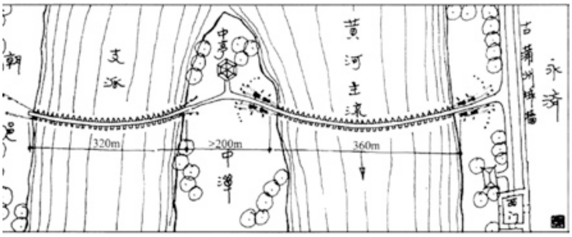



**Fig. 72** The diagram of the floating bridge at Pujindu

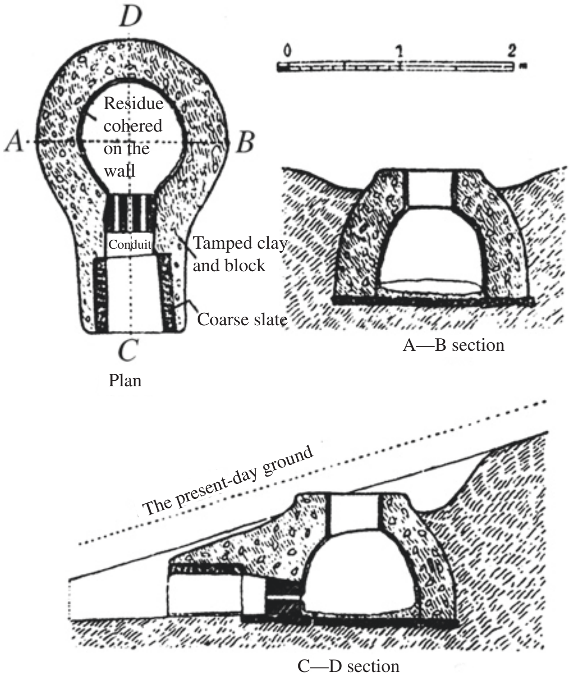



**Fig. 73** The iron smelting furnace used in Europe in ancient times

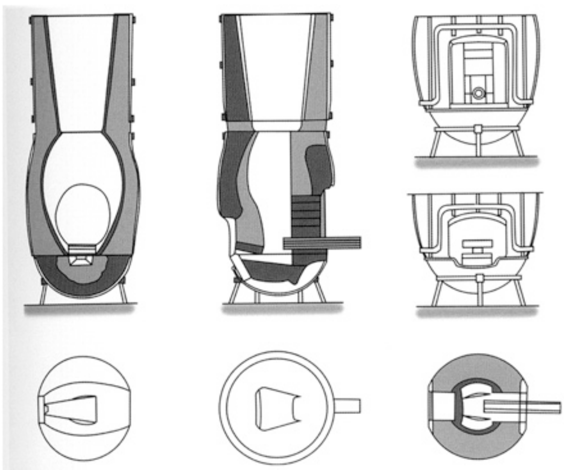


**Fig. 74** Sections of an iron smelting furnace used in ancient China

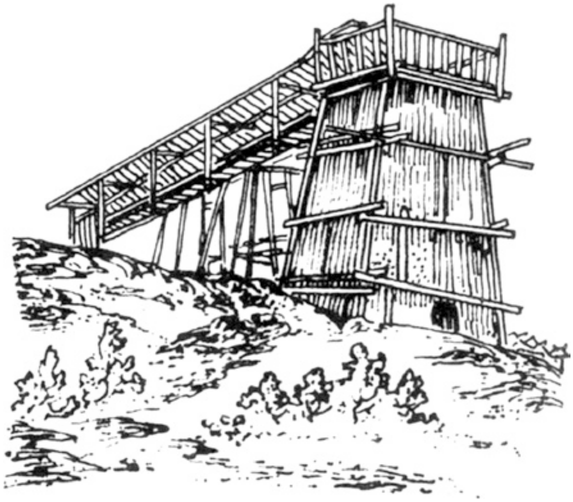


**Fig. 75** A traditional blast furnace for iron smelting used in Yunnan Province

50 cubic meters capacity, but later it had to be replaced with a smaller sized furnace due to the limitations on air-blasting. In Han-Wei Period (220–589, covering Three Kingdoms, Jin Dynasty, and Southern and Northern Dynasties), the furnace used was usually 3–5 m high with a 1–2 m bore and a 2–10 cubic meters capacity. And in Qing Dynasty, the furnace was as high as 10 meters and had a daily output of 2,000 kg iron (See Fig. 75). The fuels used during this period of time included charcoal and coke, and the flux was limestone and fluorite. By smelting with charcoal, the pig iron produced would have a high content of carbon and a low content of phosphorus and sulfur. But afterward, when coal was used as fuel from Southern and Northern Dynasties on, as shown in *Shuijingzhu* (*Commentary on the Waterways Classic*), there was a greater amount of sulfur in the pig iron produced. Techniques in air-blasting played an essential role in iron smelting. Hence, the old sayings that "good wind leads to good iron" and "where there is wind there is iron." On the excavated stone relief rubbings having the description of what happened in Han Dynasty, there are images of leather bags used for blasting air. As early as in Han Wei Period, air-blasting was already powered with water or by a horse. And for the same purpose, double-blasts bellows had been invented by Song Dynasty, which was historically significant both in mechanics and in metallurgy (See Figs. 76 and 77).

### 4.3.2 Casting with Iron Molds

Iron molds could be used to cast farming instruments, hand tools, and cart parts. The outside of an iron mold was mostly shaped similar to the shape of the iron device to be produced in order to both achieve an even heat radiation and reduce the weight of the mold. Iron molds employed in the Warring States Period were

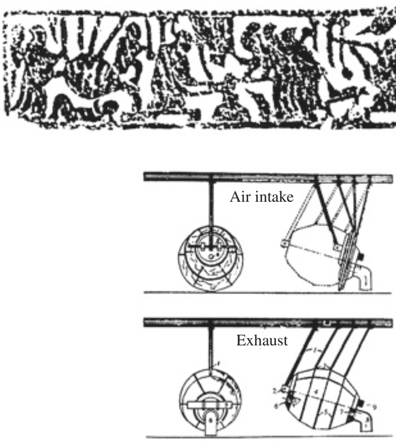



**Fig. 76** A restored image of a stone relief rubbing describing iron smelting in Eastern Han Dynasty, excavated in Hongdaoyuan, Tengxian County, Shangdong Province, and a restored image of leather bags used for air-blasting

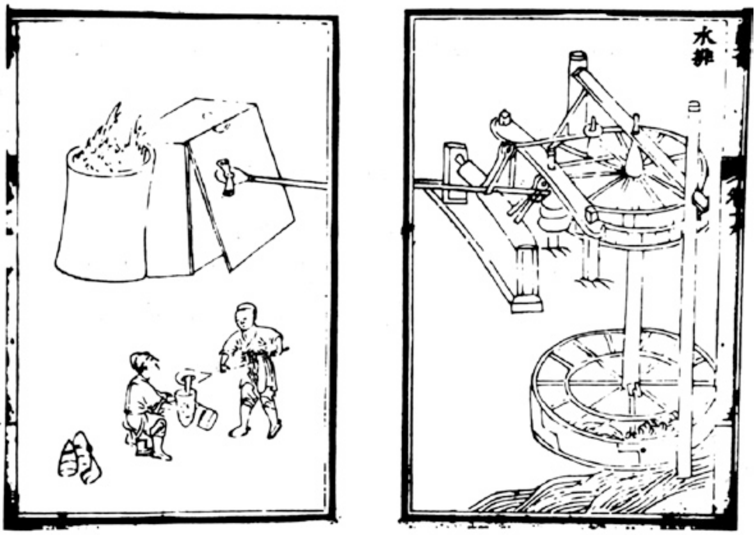



**Fig. 77** Bellows powered with water

mostly made from white pig iron (See Fig. 78). In Han Wei Period, gray pig iron was mainly used, which could lengthen the life of the mold. After Southern and Northern Dynasties, the use of iron molds decreased, and since Song Dynasty, they have been used to produce only a few kinds of devices like plow boards.

**Fig. 78** The metallographic structure (100x) of white pig iron used in the Warring States period

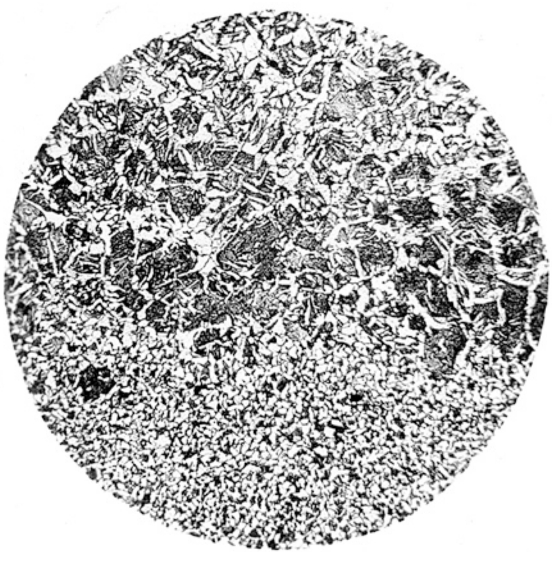


**Fig. 79** The metallographic structure (400x) of softened white cast iron produced in Han Dynasty

### 4.3.3 Cast Iron Softening

In ancient China, softening cast iron could help produce high-tensile cast iron, including white heart malleable cast iron, black heart malleable cast iron, and malleable cast iron with spheroidal graphite (See Figs. 79, 80 and 81), and the features of the graphite in the last kind were similar to those of the graphite in nodular cast iron treated with magnesium and rare earth in modern times. To decarburize, cast iron was a unique way of steel making, and the popularization of this method of

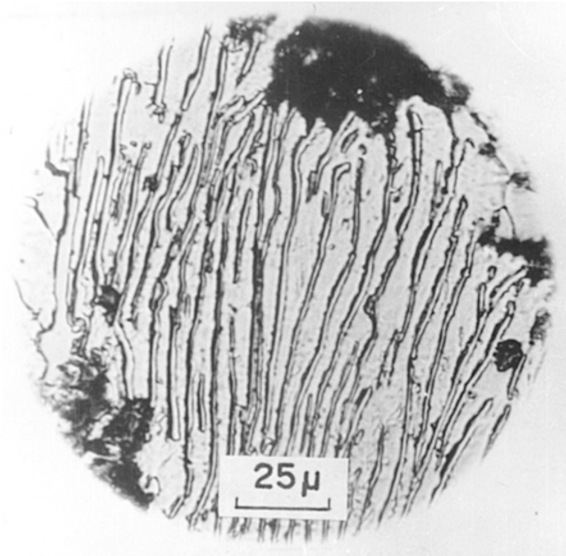



**Fig. 80** The metallographic structure (400x) of black heart malleable cast iron produced in the Warring States period

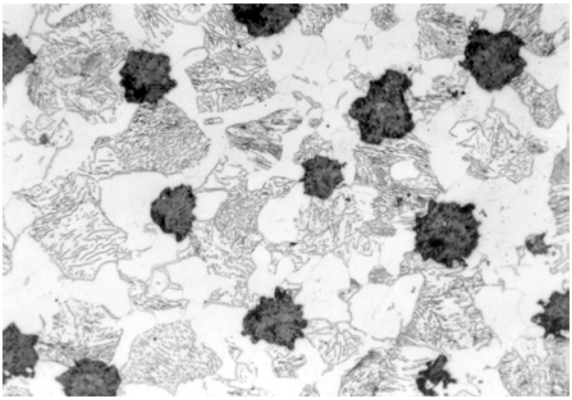


**Fig. 81** The metallographic structure of malleable cast iron with spheroidal graphite

softening cast iron was a historically significant contribution to the iron and steel making in ancient China.

### 4.3.4 炒铁 Iron Stir-frying

The invention of iron stir-frying led to the breaking of the boundary between pig iron and wrought iron, i.e., treating the two different materials within one technological system, which paved the way for the later invention of hot-metal carburized steel. The furnace for smelting pig and wrought iron as showed in *Tian Gong Kai Wu* (*The Exploitation of the Works of Nature*) connected the process of iron smelting with that of iron stir-frying. That proved to be a kind of very advanced way of processing by reducing the heat loss and improving the production efficiency (See Figs. 82 and 83).

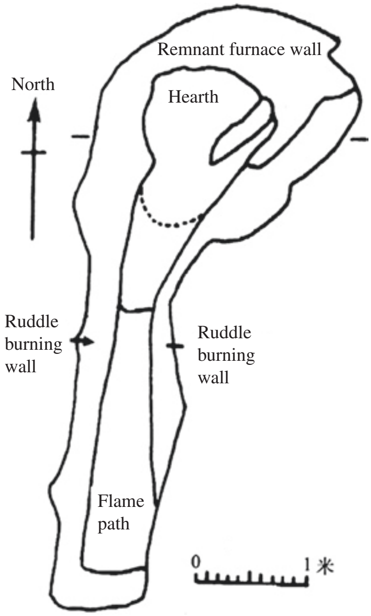



**Fig. 82** A round-shaped furnace, used in Western Han Dynasty, excavated at Tieshenggou, Gongxian County (today's Gongyi City), Henan Province

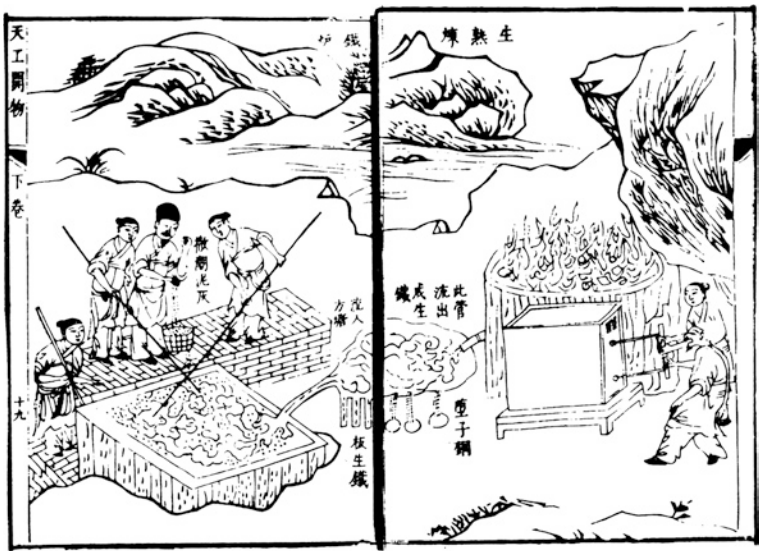



**Fig. 83** The picture of a furnace for smelting pig and wrought iron, taken from Tian Gong Kai Wu (*The Exploitation of the Works of Nature*)

### 4.3.5 One-Hundred-Times Forged Iron

According to Liu Kun in Western Jin Dynasty, forging iron one hundred times referred to a process of making iron as pliable as possible so that it could be used to wind round a finger. *Wuyue Chunqiu* says that the iron fabric pattern of the sword named Ganjiang (taking after the name of a man then engaging in smelting iron) resembles that of a turtle shell, and that of the sword named Moxie (taking after the name of Ganjiang's wife) resembles flowing water. *Yuejueshu* says that Ou Zhizi and Ganjiang produced the swords named Longyuan, Taia, and Gongbu, which all have beautiful iron fabric patterns. In Cangshan, Shandong Province was excavated a knife which had been forged 30 times in the sixth year of Yongchu, (112 DC), Eastern Han Dynasty, and in Xuzhou, Jiangsu Province was excavated a sword forged 50 times in the second year of Jianchu, (77DC) Eastern Han Dynasty. As some history books show, in Three Kingdoms, Puyuan from the State of Shu made 5,000 knives which had each been forged 72 times, and Sunquan, Lord of the State of Wu, had 3 valuable swords named Bailian (forged a hundred times), Qingdu and Loujing, respectively.

### 4.3.6 Steel Carburizing

The article *Daoming* written by Wang Can in Eastern Hang Dynasty says that to make wrought iron bendable requires pouring pig iron liquid onto it several times. And *Qiming* written by Zhang Xie in Jin Dynasty says that to enable wrought iron to bend 10,000 times requires pouring pig iron liquid onto it 1,000 times. That shows, in as early as the later Eastern Han Dynasty and the early Jin Dynasty, the Chinese were already capable of producing steel by smelting pig iron and wrought iron together. *Beiqishu* states that Qiwu Huairen, an expert at iron smelting in Northern Qi Dynasty, produced a durable iron knife with its ridge made from wrought iron and its blade made from durable forging iron. The so-called durable iron was a kind of middle-high-carbon steel resulting from smelting pig iron and wrought iron together and then being quench hardened in the liquid composed of animal's urine and animal's oil. Thus, that durable iron knife could be extremely strong and highly pliable. The article of *Chongxiu Zhenghejingshizhenglei Beiyongbencao* (a revision of the descriptions about herbals in the classical works on politics, economy, and history) quotes Tao Hongjing, a Taoist thinker in Qi and Liang Dynasties, that iron and steel technology refers to that used to smelt pig and wrought iron together so as to cast swords and knives. From that we can conclude that it was very popular to make farming instruments with hot-metal carburized steel in Southern and Northern Dynasties. *Mengxi Bitan* (*Brush Talks From Dream Brook*) written by Shen Kuo in Song Dynasty provides a detailed description of the way to produce hot-metal carburized steel (See Fig. 84), which was later to be adopted as an established steel-making method till the first half of the twentieth century.

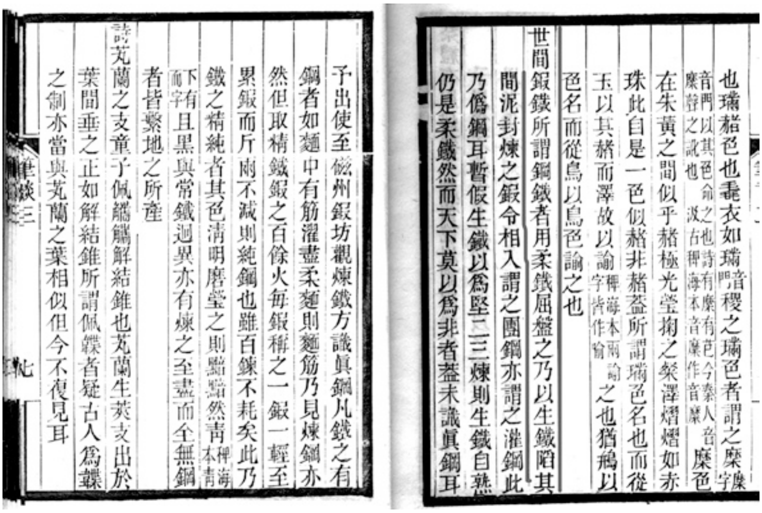

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**Fig. 84** Two pages taken from Mengxi Bitan (*Brush Talks From Dream Brook*)

#### 4.3.7 Steel Sandwiching

Tian *Gong Kai Wu* (*The Exploitation of the Works of Nature*) describes the techniques about steel sandwiching for making the blade part of an iron instrument used for farming or for other purposes. Wang Mazi scissors and Zhang Xiaoquan scissors are the representative products processed with iron pasting. The techniques about inserting pig iron for making farming instruments and tools were first shown in *Tian Gong Kai Wu*, which says that, for an iron tool weighing 500 g, 15 g pig iron needs to be inserted into it. That is, to spread pig iron liquid on the blade part of the wrought iron tool so that the carbon in the former could flow and merge with that in the latter to form a certain proportion, and in this way the tool blade would become both strong and pliable as peasants preferred.

### *4.4 Formation of Iron and Steel Technological System and Its Further Development*

1. Two Different Technological Approaches

The Western countries took a one-way technological approach in iron and steel production in ancient times, while China took a double-way approach (See Figs. 85 and 86), which approximated to the iron and steel technological system in modern times. Techniques about pig iron smelting and casting were invented in China in as early as about 8 BC, while it was not until fourteenth century in

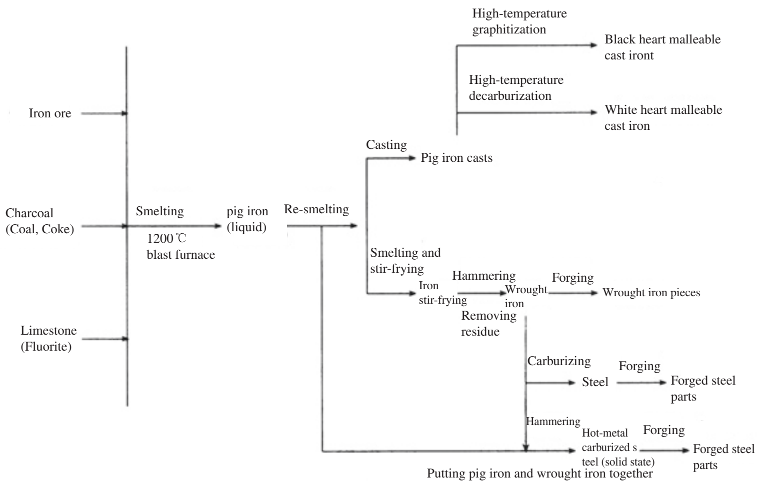



**Fig. 85** Chinese iron and steel technological approach in ancient times

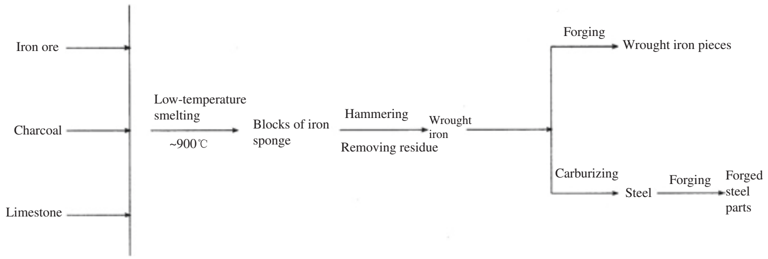



**Fig. 86** European iron and steel technological approach in early times

Europe that pig iron had been applied. About twenty-one centuries earlier, that was a big surprise in the history of iron and steel production technology. The reason perhaps lay in the differences between China and European countries in their traditions and concepts concerning iron and steel making.

In China, iron smelting originated from bronze smelting and casting, and the latter was derived from potting. The technique concerning using high temperature in potting was inherited and enhanced in bronze smelting and casting in Shang and Zhou Dynasties, especially that about the control of the temperature and air within the furnace, thus having contributed to the formation of the system of traditional techniques and processes centering on casting.

Then, that system was again inherited and enhanced in iron smelting.

In the Pre-Qin Period, when a casting worker found some iron ore, he at first would put the ore into a furnace, smelting it into liquid, and then molded the iron liquid into certain shapes. But as the pig iron devices thus cast were very fragile and vulnerable, the worker began to try to put them in a kiln, firing them 3 or 5 days until they became as pliable as he needed. That was how the ancient Chinese, without abandoning the traditional techniques and processes, managed to turn pig iron into wrought iron, or malleable cast iron, or low-carbon steel.

However, things were different in Europe. In Bronze Age, they applied both casting and forging and attached more importance to the latter, which, according to the British scholar R.F. Telicote, was a technological tradition naturally developed from the use of natural copper. When Iron Age arrived, they still focused on forging. Their practice was to obtain sponge iron by smelting the ore at low temperature, to produce wrought iron by forging the sponge iron and removing the residue, and then to perform carburization to get steel.

All of the above shows that China differed from Europe in her technological approach not because she was more advanced than the latter or the Chinese were smarter than Europeans, but because the two had different technological traditions and concepts. In a certain sense, China had no way but to take the approach she was taking. That is, while continuing to follow the traditional techniques and processes centering on casting, China also had to find some new way to fulfill her purposes. Both China and Europe experienced Iron Age, and in both places, a lot of iron instruments, iron parts, and steel knives and swords were used, but they adopted two different technological systems in producing those products. That could be described as, in *Zhouyi Xici (1)*, "different roads lead to the same destination, and different ideas are proposed to solve the same problem." That is, all roads lead to Rome. At least there were two roads leading to Iron Age, one was taken by China, and one by Europe.

But it should be admitted that the Chinese technological system was indeed superior to the European one. According to Dr. Joseph Needham, the iron and steel technology in ancient China accorded with that in modern times, i.e., first smelting iron ore for pig iron, then making wrought iron from the pig iron, and finally smelting the pig iron, wrought iron and the waste steel to produce good steel. Dr. Joseph Needham also said that, by the end of fifteenth century, no other countries than China in the world had possessed so abundant resources in the production of iron and steel. So, we can say that China held an outstanding position in the world's history about the technologies in producing iron and steel

2. Tian Gong Kai Wu says that bench work, the work of assembling machines and trimming parts, is the ancestor of all machines. That means that big things form on the basis of smaller ones. The major shift from casting to forging in producing farming instruments indicated the establishment of an iron and steel technology system, which had undergone a long time of practice, comparison, selection, and elimination. For example, before Tang Dynasty, people made iron farming instruments mainly by casting, from being able to cast a tool of half a palm in size in the Warring States Period to one as big as a full palm in Han Dynasty. With the size becoming larger, the hoes, shovels, pickaxes, or spades cast that way were felt too heavy and also too fragile to be good for use. However, things changed around the middle of Tang Dynasty when iron and steel technology had been improved. Because of the shift from casting to

forging in producing farming instruments, the size of hoes, shovels, pickaxes, or spades produced was from one palm large to one and half palm, and then to two palms or even larger (See Figs. 87 and 88). For an agriculture-based country like China, the improvement of farming instruments had always been a major issue. Obviously, the unprecedented change in social and economic development from Tang and Song Dynasties forward had something to do with the major technological shift in producing farming instruments. After the middle of Tang Dynasty gradually formed a technological system in which

**Fig. 87** An iron hoe that is 63.7 cm long, produced in Northern Song Dynasty, excavated in Henan Province

**Fig. 88** An iron spade produced in Northern Song Dynasty, excavated in Jinan, Shandong Province

the major part was first smelting ore in a furnace to get pig iron, then turning pig iron into wrought iron, and finally smelting pig iron and wrought iron together to get steel, and the minors included performing carburization for steel and steel inserting and pasting. That system of traditional technology was followed for generations as an established way to produce iron and steel, which was mentioned in many classical works like Tujing Bencao written by Su Song in Song Dynasty, Chunmingmeng Yilu by Sun Chengze and Tianxia Junguo Libing Shu by Gu Yanwu in Qing Dynasty. That was a summarizing achievement in the history of China's iron and steel technological development, thus making China rank high in the iron and steel technology in the world. In the system, the fundamental part was smelting ore to get pig iron, but the invention of performing carburization for steel was the main factor contributing to the establishment of the system and its long standing. The process of smelting pig iron and wrought iron together to produce steel, as stated in Tian Gong Kai Wu, was a vivid description of the technological ideology about iron and steel production in ancient China.

3. The core of the technological ideology in ancient China can be summarized in the character He (a well-integrated whole). Kao Gong Ji states that only by adapting to the certain season and weather, by using select material and having good workmanship could a best quality product be produced. It also states that, when making a bow, the worker should not only prepare all the six kinds of necessary materials but should also be able to skillfully integrate them in the process. Treating pig iron at high temperature and turning it into pliable but strong malleable cast iron was a process of turning the unsuitable into the suitable. The making of a durable iron knife, as described in Beiqishu, with steel produced by smelting pig iron and wrought iron together was consistent with the ancient ideology that everything can be made only by the integration of Yin (negative factors) and Yang (positive factors). Iron-inserting was to make the blade part of an instrument with steel, and the other parts with wrought iron so that the instrument would have a strong blade but be pliable in other parts.

Like cooking that requires the integration of steaming, sir-frying, boiling, simmering, and adding various seasoning for a well-integrated whole of all necessary Chinese elements for a typical Chinese dish, iron smelting also requires the integration of all the processes. In the eyes of ancient Chinese, everything went the same way. That was why there were many like terms used in iron smelting and cooking. Iron stir-frying was one example. In Song Dynasty, the blast furnace was called an ore-steaming furnace, that is, to get iron, the ore needed to be steamed or boiled. And among the people, performing carburization for steel was called simmering iron for steel.

4. Pot Casting

Why do the Chinese usually stir-fry vegetables rather than fry beef as Europeans often do? It is the traditional technology to produce iron and steel, which exerted significant impacts on their daily life.

Chinese people cooked meals and fried dishes by using iron pots. Iron pots were cast with mud molds. A set of mud molds could be used again and over again for a hundred times (See Fig. 89). In Qing Dynasty, at Wang Yuanji workshop in Wuxi, Jiangsu Province, Chanlu (a small-sized furnace) was used to smelt iron and the temperature of the iron liquid could be up to 1,400 °C. The iron pot cast there was only 0.15 mm thick in its thinnest part, and the material used to make the pot was gray heart malleable cast iron. According to some experiment, a pot of 40 mm in diameter they had cast still kept intact when it had been pressed into one of 30 mm in diameter. According to Mr. Han Binggao from the Technological Department of Machine Building Ministry, the iron pot he had taken from China into the USA where he did his fieldwork greatly surprised Americans, and they later put it in the museum of Chicago. Using an iron pot to cook, one can jolt the pot when stir-frying vegetables since the pot is quite light. Why do the Chinese usually stir-fry vegetables rather than fry beef as Europeans often do? That is owing to our early invention of iron smelting. As far as the ways of cooking in China were concerned, Shang and Zhou Dynasties saw no stir-frying but steaming and barbecuing. Stir-frying began to be adopted in Han Dynasty when good but cheap iron pots had been produced. It was the integration of iron pot, steel knife, stove, coal, and cooking oil that had brought stir-frying, a new way of cooking, into being in Han Dynasty. Now, in China, dishes cooked by way of stir-frying take up more than 60 % of all the dishes on a dining table. Since there are no iron pots but pans for Europeans to use, they do not stir-fry vegetables but fry beef. Similarly, some Chinese minorities like Yi people have no iron pots and so they do not stir-fry vegetables either. According to Mr. Song Zhaolin, an ethnographer, nomadic people mostly adopt steaming and barbecuing rather than stir-frying in cooking. As to the knife, the Chinese are very particular about the skills in using a knife in cooking, and as the knife they use is made by way of steel inserting, it helps them to cut meat or vegetables very easily. So, we should say that the invention of steel inserting was, to some extent, to meet the cooking needs of the Chinese people. Besides, unlike a knife of the Chinese style, the

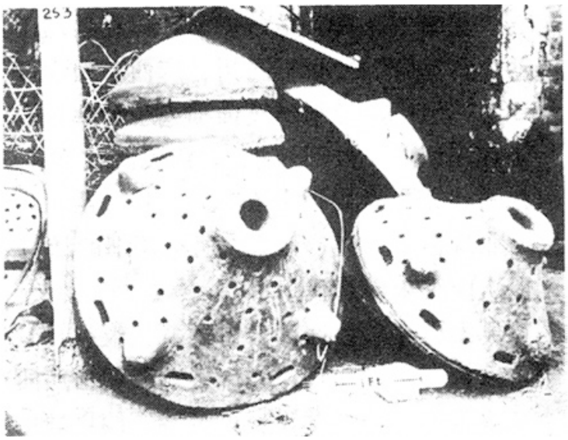


**Fig. 89** Mud molds used to cast iron pots

knife produced by Europeans is often a long narrow piece thus not as convenient as the Chinese one in cutting meat or vegetables. Chinese students overseas often cook Chinese food so that they have to buy a knife of the Chinese style, and also soya sauce, cooking wine, and vinegar. Otherwise, the dish they cooked could not become one of a well-integrated whole of all necessary Chinese elements for a typical Chinese dish.

5. Needle Making

There is an old saying that an iron stick could eventually be ground into a needle so long as enough efforts are made. But as a matter of fact, a needle is made not by grinding an iron stick but by drawing fiber from a steel ribbon. There is a picture showing the needle-making process in Tian Gong Kai Wu. That is, first, drawing a steel ribbon into a thinner piece and shaping it into needles; next, putting the shaped needles in a cauldron to heat them slowly (a process of annealing in order to get away with work-hardening); then, covering them with soil, charcoal and fermented soya bean, and steaming them (a process of carburizing); finally, quenching. An American scholar named R.P Hommel says in his work *China at Work* that Chinese people are ignorant of any techniques in fiber-drawing. But that is not true. In Song Dynasty, Shaofujian (one of the government departments supervising handicraft industry at that time) had a branch supervising the work concerning fiber-drawing. According to the information on the bronze template used by the Gongfu Needle Workshop in Jinan, Shandong Province, to print advertisers (the template is now on display in the National Museum in Beijing) in Song Dynasty, the workshop often bought high-quality steel ribbons to make its thin Gongfu needles. In Ming Dynasty, there was a place called Tiexian Lane (a lane full of workshops specializing in fiber-drawing) in Hang Zhou, Zhejiang Province. And, at that time, the imperial palace included a department supervising the work involving fiber-drawing, classifying the products into "soy bean ribbons," "green bean ribbons," "glutinous millet ribbons," and "millet ribbons." In Qing Dynasty, there were many fiber-drawing workshops located at Daiyangzhen, Jincheng, Shangxi Province, and also many at Foshan, Guangdong Province. Small as it might, the needle was indeed a necessity in each and every household in the country. At the end of Qing Dynasty, a German scientist named Ferdinand von Richthofen investigated the needle-making industry at Daiyangzhen and concluded that the needles produced there were being used by billions of people in China. But, formerly known as the capital in China in producing needles, Daiyangzhen declined at the end of the nineteenth century. In 1867, China imported from Europe 0.2 billion needles. But in 1891, the number of needles imported increased to 3 billion, 7.5 per person on average. With that large number of European needles being dumped in China, there was soon no market for the steel ribbons produced in Shaoyang and Xiangtan, Hunan Province and Wuhu, Anhui Province. As a result, the needle workshops at Daiyangzhen and Fushan had to be closed one by one. In 1909, the last agent for needle workshops in Shanxi left Wuhu, marking the complete decline of the traditional needle-making industry in China. Generally, the entire traditional iron smelting industry in China shared the similarity.

Owing to the uneven social and economic development in China and to the inherent vitality of the Chinese traditional metallurgy, some techniques had been employed for quite a long time. Let us take the fishing hooks used by the Hezhe people in Heilongjiang Province. They first bought steel ribbons from the Han and processed them into hooks. Then, they put the hooks together with charcoal and potassium nitrate into a clay jar and heated the jar. After a certain while of heating, they broke the clay jar into pieces and cooled the hooks in the water. Finally, they stir-fried the hooks in an iron cauldron, together with some soy bean oil and millet (the process of tempering). Using the fishing hook produced that way one could catch a fish weighing around 500 kg. That was a record written in the 1950s during a research on the life of minorities in China.

Chapter Three Remaining Traditional Metallurgical Crafts

## 4.5 Gold Mining and Smelting in Zhaoyuan

It is said in *The Exploitation of the Works of Nature* that the best gold is 16,000 times higher than iron in price. Nearly 100 thousand tons gold has been mined in the world since the ancient times. In 1848 and 1851, gold mine was found in San Francisco, USA, and in Melbourne, Australia, leading to a gold rush in the both places. Hence, the name of Jiujinshan (Old Gold Mountain) given to the former, and Xinjinshan (New Gold Mountain) given to the latter.

Zhaoyuan, Shandong Province is famous for producing gold in our country, and the mines at Fushan and Linglong within Zhaoyuan have been awarded the title of the Best Gold Mines of Asia. Judging from the burn marks in the ancient craters and the remnant iron chisels and iron hammers found there, we can conclude that, in as early as the Warring States Period, explosion was used for mining gold in Zhaoyuan. In the fourth year of Jingde (1007 AD), Song Dynasty, the Minister Pan Mei was supervising the operation of gold mining in Zhaoyuan, and gunpowder was then used for the explosion. In Ming Dynasty, Emperor Shi Zong (1522–1566) ordered that gold be mined to help the industrial development in general, and as a result, gold mining in Zhaoyuan became all the more prosperous.

The traditional crafts for gold mining are still being used in Jiuqujiangjiacun Village, Fushan Town. The main processes are as follows:

Step 1 Mining and hammering. After mining the ore, hammer it into ore grains, with each about 1 cm in diameter.

Step 2 Grinding. Add water to the ore grains, stirring them until they are evenly mixed with the water, and then grind them into powder. The concentration ratio in ore dressing depends on the fineness of the ore grains. Grinding the ore grains by pushing a stone mill was really a painstaking job. Usually, the people pushing a mill tried to reduce their fatigue by singing songs or telling stories. And many women had their legs deformed because of doing this job for years.

Step 3 Laliu (a common name for gold ore dressing). For gold ore dressing, a 2.5 m long and 1 m wide slide board (which is usually made from willow wood, because it has a rough surface, thus easily holding gold grains) is used when placed in an inclination of 15°–18°. Take the ore pulp with a spade, put it onto the upper surface of the slide board, and press several ditches on the pulp with a rake. While the water is flowing along the ditches, rake the pulp so that it can flow down with the water. In this way, gold concentrate will remain on the upper surface of the board, and the lighter gangue will be poured down by the water and then to be swept into a puddle of waste sand grains. Put the gold concentrate (commonly called Jinni) in a mud bowl, and after it is heated dry, sweep it onto a piece of paper with a rabbit leg (because it cannot stick gold grains). Then, wrap the grains in the paper for further processing.

Step 4 Smelting (commonly called Lahuo). Light a stone stove and put the paper bag containing Jinni into a crucible on the stove. After the Jinni has melted and the residues have gradually evaporated, add glauber salt and borax to make slag and purify the Jinni. Then, put the purified Jinni into the mold to form a gold ingot. The success of all the above processes depends on the experience and skills of a gold artisan, and so they are typical intangible cultural heritage.

The traditional crafts for gold mining and smelting have been passed down from generation to generation within families. Now in Jiuqujiangjiacun Village, the villagers Wang Jinyong and Chi Mengwen are their respective families' seventh generation gold craftsmen, and the first generation of their families' engaging in the job can be traced back to the 1770s–1780s. Wang Jinyong, now 47, began to learn from his father how to mine and smelt gold when he was 18. As a senior engineer holding a BA, Wang is now director of the Production and Technology Institute under the Gold Mining Company. So, he is a highly educated new generation inheritor of the traditional gold crafts.

Zhaoyuan has remained to be the biggest place for gold mining, with its yearly gold output taking up 1/7 of that of the whole country. In 2002, it was awarded the title of Gold Capital of China. However, machines have been replacing the traditional crafts in gold mining and smelting since 1960s, and most of the experienced gold craftsmen there are already in their 60s. Hence, it is extremely necessary for the government, the enterprises, the communities, the experts as well as the craftsmen themselves to preserve and carry on that precious cultural heritage.

## 4.6 Zinc Smelting in Hezhang

The traditional zinc smelting was carried out mainly in Guizhou, Yunnan, and Hunan Provinces, especially, in Hezhang, Guizhou. According to the investigation conducted in the 1980s by Mr. Xu Li about zinc production in Magu zone, Hezhang, zinc was obtained from the ore taken from the local zinc and lead mines, which was composed of smithsonite (calamine), hemimorphite ($H_2ZnSiO_5$), and zinc sulfate ($ZnSO_4$), containing 16–20 % zinc. For retrieving zinc vapor, an 80 mm-high jar was used, which was made from refractory clay and clinker and had a container on its upper part. The furnace to smelt zinc (commonly called a Manger Furnace) was rectangular, 10 m long and 1.5 m wide, with capacity of 120 jars. The following were the smelting procedures. The zinc ore together with coal were broken, mixed, and put into the jars. The jars were put on a layer of coal and clinker inside the furnace, surrounded with coal cakes; then, they were spread over by another layer of clinker, and finally covered with slurry. The furnace was lit, and the temperature was increased. When zinc was reduced from the ore at high temperature, the exhaust would escape from the vent on the lid of the jar and ignite, and the zinc vapor would collectively remain in the lower part of the container to be taken out after the shutdown of the furnace. Zinc obtained this way would be as pure as 97–98.7 %, having a small amount of lead and iron. The residue could still be put into a crucible to be recycled to get the remaining zinc. The furnace was fed with 700 kg ore each time, yielding 85–90 % zinc, and the production process took nearly 24 h. Sixteen people were required to operate the furnace as well as to make the jars.

Both the Daoguang Taidingfu Annuals and Weiningxian Annuals compiled in Qing Dynasty say that Tianqiaoyinchanggou (in today's Magu zone, Shashi township) produced zinc, and its mining was started during Tianfu period (936–947), Five Dynasties. That is a very important clue about the invention of zinc smelting crafts in our country, and it can be used as an additional reference to compare the description about zinc in Baocang Changweilun written in the second year of Qian Heng (918), in which Xuan Yuan of the Five Dynasties says that zinc can help get gold, refer to *Compendium of Materia Medica*.

Viewed from the history of technology development, the traditional zinc smelting crafts in Hezhang and Huize are too outdated and too pollution-causing to be continuously practiced, but they are really of great value to the study of the origin of zinc smelting and of the development and dissemination of the concerning crafts. Thus, they are precious historical data to be preserved.

## 4.7 Casting Plows with Stone Molds in Qujing

In as early as Bronze Age stone molds were generally replaced by clay molds, but the former can still be seen today in Yunnan and Sichuan where they are used for casting iron plows. That is really a miracle in the history of technological development, and those stone molds can be taken as living fossils showing the ancient crafts. Wang Dadao and Li Xiaocen, respectively, investigated stone-mold casting practiced in Dongjiacun Village, Zhujie Qujing, Yunnan Province, having attracted attention in academic circles. In Dongjiacun Village, a family named Yuan has been casting plows with stone molds for generations. Born in Henan, their ancestors were forced to join the army in Yunnan 100 years ago, and since then have settled in Zhaizikou township, Baishui chengguan zhen, Fuyuan. Since the crafts were only passed down to descendants according to the custom, when Yuan Chengde, the sole heir of the family died in 1992, Xu Zhongheng, the husband of Yuan Chengde's sister, who had learned the crafts from Yuan's uncle since 1949, succeeded his brother-in-law. In the 1980s, Xu led three men to cast iron plows in many places within Fuyuan county, including Yingshang, Dahe, Huangnihe, Yuwang, and Laochang. They each got a monthly pay of RMB 100 yuan, together with free room and board, given by the local peasants for casting iron plows. Although 500 iron plows were produced a month on average, it could hardly meet the demands. Their daily output was 40 iron plows. As one plow sold 1.5 RMB yuan, they each could earn nearly 15 RMB yuan one day. Right now, there are still a dozen of stone molds in Xu's house, but he has not practiced the crafts since 1996. The main processes of casting iron plows with stone molds are as follows:

1. Mold Making and Repairing. Since stone molds had to be fire-proof, i.e., when heated, they would not split or crack, they were made from white sandstone and red sandstone (but they must be free from layers), which had been taken from Shenjiacun Village at the border between Zhanyi and Xuanwei. In the course of making a stone mold, one side of the stone was chiseled flat and the opposite side was chiseled into the shape of a plow. The stone mold weighed nearly 40 kg, and it needed repairing with refractory mud after being used for casting. And when there were serious hollows on the stone mold after it had been used for a period of time, a heavy repair was required. In the course of repairing the mold, unprocessed material was used to mend the hollows first, and after it was heated dry, level it out, and finally coat it with ashes of the burnt Longzhaocai (a plant). A well-maintained stone mold could be used for 50 years, while a badly kept one only half a year. The core of the mold was a frame made with iron plates, which, from the top to the bottom, were coated with many layers of the mixture of coke powder (taking up 80 %) and white refractory mud (taking up 20 %). After each layer of the mixture was coated, it would be heated dry, and when all the layers were finished, the dried mixture would be cut into the certain shape.
2. Mold Drying and Connecting. Being put on an iron frame, the parts of a mold had to be dried 2–3 h by firing firewood. Only after the water was removed from them, could they be prevented from cracking when used for casting. The core support had to be coated with dark mud repeatedly while being dried. Then, there followed the connection of the parts. The upper part of the mold had to be connected with the lower part after the mud core support was inserted in between. At this time, the core support would be pressed flat and bonded to the core and the upper part of the mold. The gap between the core and the mold was the thickness of the plow as well as the funnel. After the connection, the mold would be bound with sheet iron on its waist part. To make it bound more closely, between the mold and the sheet iron would be inserted some iron sticks which were fastened with wedges. Before pouring metal liquid into the mold, the mold had to be inclined at about 80°, with its funnel facing up. If the mold had been erected earlier than it should have been, its own weight would have made the core support removed from its right position, thus causing a failed casting.

3. The retort furnace used for casting iron plows with stone molds was commonly called Bagualu and had many unique characteristics. A crucible was connected with the bottom of the retort, and to prevent rifts, the connected part was coated with yellow mud which was dried with slow fire. After warming-up the furnace 20 min, small pieces of iron were put onto the coal bed within the furnace and the bellows were started. When the pig iron melted, it flowed into the crucible. After raising the crucible by putting an iron stick with a tenon into the square hole of the crucible, and removing the slag, it was ready to pour the iron liquid into the mold. Pouring iron liquid should be fast at first, and then slow down. To prevent the core from being raised due to the buoyancy of the iron liquid, it should be pressed with a wood stick. In nearly 1 min after the finish of the iron liquid pouring, the core would be taken out by using a wood stick which had been inserted into the holes on both sides of the core. Then, after 2 or 3 min, the mold would be removed and the cast would be taken out. After knocking down the burrs, a desired cast product was obtained.

At least 3–4 people were required to complete the whole process of the casting. The iron used to cast plows was sold at a price of 3 RMB yuan per kilogram. The furnace needed to be started up on a double-numbered day or a lucky day. Before the start-up, people were required to worship Taishang Laojun (the supreme god), asking for His protection by contributing to Him chicken, wine, and cooked dishes, as well as firing some yellow paper and lighting 3 incense sticks.

## 4.8 Techniques of Pig Iron Casting at Yangcheng

Yangcheng in Shanxi Province had remained to be a major site for iron industry. The techniques for casting iron with square furnaces and Li furnaces, for iron puddling, stir-frying, and casting, and for making iron molds and casting plow-boards had all been used there. Among the techniques, those for casting iron with Li furnaces and casting plow-boards with iron molds had been practiced until the 1990s, which can be regarded as the representative of, and the living fossil for, the Chinese pig iron-casting techniques (See Fig. 90).

Casting Iron with a Li Furnace

Li furnace, 3 m high, was composed of the upper, middle, and lower parts, with its inside walls curving. It was made of processed quartz sandstone, commonly called “precious stone.” The fuel was charcoal which was composed of 70 % burned wood and 30 % wooden stubble. Such kind of charcoal was strong and tough when put under pressure. The ore was mostly iron-rich hematite, which had to be broken into pieces and heated at high temperature to remove sulfur before it was put into the furnace.

After the furnace was lit and the temperature reached to a certain point, iron ore and charcoal were put into the furnace. Approximately every half an hour, 10–15 kg qualified iron liquid was taken out of the furnace. Stokehole control of

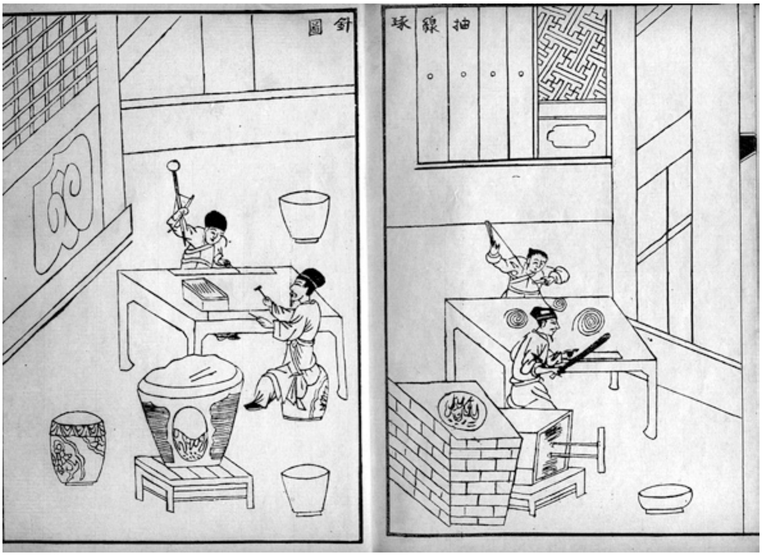



**Fig. 90** A picture showing the process of fiber-drawing in making needles, taken from *The Exploitation of the Works of Nature*

the iron liquid composition was commonly called "examining the color of fire" and "examining the color of water." By "examining the color of fire," it was meant to judge whether the fire went well and whether the iron liquid composition was as good as required by looking at the fire flames coming from the taphole and looking at the shape of the iron liquid within the furnace. By "examining the color of water," it was meant to take out a spoon of iron liquid out of the furnace and blow the surface of the liquid with one's mouth. If the color was red touched with gray, that meant there was graphite flowing on the surface, indicating a high content of carbon. This kind of liquid was called "Rangshui." The furnaceman who was responsible for examining the fire color and the liquid color was named fire-examining master. Such traditional stokehole control was only dependent on the master's practical experience. Characterized by its simplicity, accuracy, rapidity, and high efficiency, it was really unique and ingenious.

Casting Plow-boards with Iron Molds

The iron mold used to cast plow-boards was commonly called "Hezi," provided only by a family named Li in Shangqin Village. The iron mold was made in the way that, first, a sand mold was made on the basis of a real plow-board through several molding, and then iron liquid was poured into the sand mold to produce an iron mold. The process was easy to operate, and so it reflected some ingenuity. A high-quality iron mold for casting plow-boards could be used for a dozen years, and it was subject to more than 20,000 times of plow-board casting. The iron mold was mostly made from gray pig iron which had a long useful life because of its heat stability, intensity, and tensile strength.

Before pouring iron liquid into the iron mold, the mold had to be preheated and be coated with a sticky material made from Guanjing (a kind of plant) charcoal. When pouring iron liquid into the mold, the workmen showed their high skills by stepping on the mold to prevent the liquid from running out. Soon after the pouring of iron liquid, the mold must be opened and the cast plow-board must be taken out. After the burr and rag being cut off, a product would be obtained. The plow-board was made from high-carbon and low-silicon white pig iron which was brittle and hard, and so, when the plow was used in plowing the field, soil would not stick to the board. Besides, the plow-board was low priced, thus well-accepted among the peasants. Generally, more than one hundred kinds of plow-boards were produced to meet the varied farming demands because of the varied soil, crops, and techniques in different places.

There were well-recognized 10 standards for acceptance of a quality plow-board. It would be rejected when it appeared to contain dark threads, its surface did not feel smooth, it had broken blade, it should crack when being heated, with edge out of round, with unequal blade, it did not give out a clear sound when being hit, it was deficient due to the insufficient pouring iron liquid, with any sand holes in it. Just because both the producers and sellers firmly stuck to those standards and requirements, Yangcheng plow-boards had been enjoying a reputation of good workmanship and reasonable price, remaining to be a unique brand product in the world.

With the social transition and the popularization of farming machines, the demands for plow-boards were sharply reduced, thus causing a drastic shrink of the industry. In the late 1980s, there were still a few Li furnaces to be put into production in the regions like Henghe, Sanglin, and Majia, but all of them have ended their production over the recent years. In 2006, the technique for casting plow boards with Li furnaces was designated as part of the first batch of national intangible cultural heritance (No. 385). Under the support of the Yangcheng government, the Institute of Natural Science History of the Chinese Academy of Sciences and Academy of Arts and Design, Qinghua university co-mounted an exhibition about the pig iron-casting techniques practiced in Yangcheng with a view to preserving the techniques by way of cultural memorization. That exhibition was hailed by the masses. The technology replacement was inevitable in history, but the scientific gene contained in the traditional techniques as well as the devotion showed and the contribution made by those who practiced the techniques are indelible and will forever be remembered by the general public.

## *4.9 Wax-Molding*

Those places well known for using lost wax-casting techniques in the traditional industry of metal smelting and casting included Beijing, Wutai in Shanxi Province, Duolun in Inner-Mongolia, Weifang in Shandong Province, Suzhou in Jiangsu Province, Chengdu in Sichuan Province, Baoshan in Yunnan Province, Lasa in Tibet, and Foshan in Guangdong Province. In the winter of 1965, during

**Fig. 91** A Bronze Buddha with a pulp mud core

our survey of the traditional lost wax-casting techniques, Mr. Wang Ancai and the author found Mr. Men Dianpu, who had been working in Beijing Micro Motor Factory since he shifted from the work of making statues of Buddha many years before. Under Men's guidance, we produced a lying Buddhist Goddess Guanyin in the Buddhist statue style of Northern Wei Dynasty by using the wax-molding techniques. The processes were as follows:

1. Core making. The core was made from pulp mud, with the iron wire bones put inside (See Fig. 91).
2. Wax mold making. The wax was a mixture of paraffin, rosin, and bean oil. After it melted and cooled down a bit, repeatedly pulled and extended it until it became fantastically plastic. Then, roll and pressed it with a stick into slices to past onto the core then. Next, adjust the slices to the desired shape by slightly pushing with a pusher. Finally, wedge some bronze supports into certain parts of the wax mold.
3. Mold preparing. Coat the mold with refractory slurry on the surface and repeat when the coating becomes dry. The front part was coated with pulp mud, and the back part with hair-fibered plaster. When the mud dried in the shade, heat the mold to remove the wax. Then, put it into the kiln to bake.
4. Yellow brass casting. Melt the yellow brass in a crucible. When the temperature for baking the mold reached nearly 300 °C, take out the mold from the kiln, and put it into the sand pit for hot casting.
5. Finishing and coloring. When the cast cooled, remove the mold and the core as well as burrs. Then, finishing and polishing should be carried out with a chisel on the parts like face, hair, and ribbons. The way of coloring was commonly called "Qianghuang," which was what Master Zheng Guanghe, then living in Jugongzi Lane, had inherited from his ancestors and was kept unknown to other people when being practiced. It was said that the bronze cast would be boiled in an herbal decoction of 3 kinds herbs to color the cast golden yellow. In this way, the color and the texture of the cast would appear much better than it was treated by electroplating. And, there would seem to be some colloid on its surface so that the cast could keep intact for a long time (See Fig. 92). However, that technique now has fallen into oblivion.

Mr. Men Dianpu died from some disease in 1973, and now there are no inheritors of his techniques in Beijing. According to a recent survey, only a few people in Foshan, Guangdong Province, and Deqin, Yunnan Province, are capable of using those techniques. Perhaps the techniques promoted in the Chinese Traditional

**Fig. 92** The colored lying Bronze Buddhist Guanyin

Crafts Society and Hangzhou Junhua Sculpture Company in 2007 would be inherited and carried forward under the new historical circumstances.

## *4.10 Iron Forging*

In The *Exploitation of the Works of Nature* written by Ying Xing in Song Dynasty, there is a quoted proverb saying that bench work (the work of assembling machines and trimming parts) is the ancestor of all utensils. Since Tang Dynasty, blacksmith shops and mobile blacksmiths had been seen everywhere in China, having played an important role in benefiting the people's livelihood. With the rapid industrialization in recent years, the iron forging industry has been falling in decline. But in some remote and bordering areas, there are still some people making a living as blacksmiths. Some of them, we should say, will not easily disappear because their existence is indispensable to the life and to the customs of the people of the areas where they stay. Take making the broadswords carried by Baoan ethnic group as an example.

Baoan ethnic group mainly lives in the three villages named Ganhetan, Meipo, and Dadun situated in Jishishan ethnic groups of Bao'an, Dongxiang, and Sala autonomous county, Gansu Province, commonly called "Bao'an San Zhuang." Of the three villages, Ganhetan has the greatest number of broadswords makers (about 620), who make more than 40,000 broadswords a year, occupying a very important position in the economic life of people there.

Having a sharp and durable blade, the Bao'an broadsword reflects excellent workmanship and remains to be both a life necessity and an ornament for the minority of Bao'an, Dongxiang, Sala as well as Tibetan and Tujia nationalities. During the Cultural Revolution, the production of broadswords was condemned as "the tail of capitalism," and therefore, the forging furnaces were destroyed and the tools were confiscated. But many broadswords makers, as they were reluctant to let go of the techniques handed down from their ancestors, kept on the production. Since the economic reform and opening up in 1978, the types and patterns of broadswords produced have been increased to a dozen. Among them, the most famous is the Boriji sword, and the most beautiful is the Shiyangjin sword.

The Bao'an broadswords are delicately forged with quality steel. The charcoal used is produced by burning black thorn trees and birch wood. Let us take the production of a Shiyangjin sword. The processes include making the blank, the handle, and the sheath. The making process of the blank consists of cutting steel, heating and forging, grooving and slotting steel, shaping, engraving breech, rough grinding, engraving blade, engraving name, engraving pattern, fine grinding, drilling holes, quenching, fine forging, and polishing.

The name given to a broadsword depends on the type or pattern of its handle. The beauty and neatness of the handle is one of the important criteria for judging the performance and skills of a sword maker. The main processes include tailoring ox horn, making the hand-guard and the screwed gripe, nailing the bronze lid, grinding the handle, engraving patterns, and fine grinding. The sheath is made from bronze plates by tailoring, wrapping and shaping, fine grinding the sheath surface, and coloring the sheath blank golden yellow by putting a hot iron stick into the sheath.

There have been many restrictions with respect to broadsword production. For example, learners of the techniques are restricted to those within the teacher's ethnic group. And when following a master maker, the apprentice has to undertake something little related to making broadswords during the first year, and only during the second year is he taught the techniques and paid for what he has done. The one who has completed his apprenticeship has to ask for his master's permission before he starts up to operate the furnace and make broadswords; otherwise his mater is entitled to break his furnace. In the past, women were prohibited from presence at the site of broadswords production, especially the one who had just given birth to a baby and the one in her menstrual period. Women were also forbidden to straddle the equipment and tools used for making broadswords. Today, apart from Bao'an people, some people from the Han are also practicing the techniques, for example, the brothers Liu Wenzhong and Liu Wenji at Ganhetan, who have been making broadswords for more than ten years.

In June of 2006, the techniques for making Bao'an broadswords were put on the list of the first batch of our national intangible cultural heritage (No. 392). With the concerted efforts of the government, the communities, the experts, the craftsmen, and technicians, those precious techniques will certainly be enhanced and continuously developed.

## *4.11 Gong-Making at Zhangzi*

Zhangzi County, Shanxi Province, was in China the earliest site where loud bronze musical instruments were made. In the first year of Zhenguan, Tang Dynasty (627), the bronze gongs produced at Chengcun, the southwestern part of Changzi county were already enjoying a good national reputation. The main processes for making a gong are as follows:

Step 1 Melting materials and making the blank. An alloy of 77 % red copper and 23 % tin is melted to make the blank. The blank is made with an iron mold. The alloy is melted in a pit furnace within which are put two crucibles, one sitting on the other.

Step 2 Hot forging. Heat the bronze blank until the temperature reaches 600 °C. Then, hot forge it so as to make it thinner and longer. This process shall be repeated several times.

Step 3 Forging into shape. For example, to forge the edge of a bronze gong, it has to be annealed and forged several times and trim it into neat shape.

Step 4 Hardening. Heat the forged musical instrument until the temperature reaches 450 °C and then harden it in water.

Step 5 Shaping by cold-forging and then tuning. As musical instruments of different shapes and sizes are different in their fixed tone scale, any of them shall be repeatedly forged and tuned to find out the tone and timbre in consistence with its tone scale.

Step 6 Polishing. Scraping the front and the back parts of a musical instrument with a scraper to make the parts become brighter is called “Guaming.” During that process, tuning is made for the first time by hitting various parts with a hammer to adjust the thickness of the parts and hammering each part until it can produce a loud and clear tone.

Step 7 Hole drilling. In the instrument, a hole is drilled and a thread is pulled through the hole so that the instrument can conveniently be carried and also can be prevented from echoing.

Step 8 The second time tuning commonly called “Mingluo Dingyin.” That is the most sophisticatedly technical process in making loud bronze musical instruments. Just as the old saying goes, making a gong requires hitting it a thousand times but determining its tone scale requires only one critical hit. The one who can do the tone determining is called “Haobashi” (a good master) or “Quanbashi” (an all-round master).

The loud bronze musical instruments made at Zhangzi are of a dozen kinds, such as flat tone gong, high-pitch gong, tiger tone gong, clear-the-way gong, big cymbals, and small cymbals. Now in the village, there have only been three craftsmen left who possess all the expertise in the gong-making, one already 81 years old and the other two around their 70s. Thus, it is an urgently necessary to carry forward the skills and techniques.

## *4.12 Gold Foil Making*

The traditional way of making gold foil was called “Bojin” (thinning gold), and many ancient books like *The Exploitation of the Works of Nature* and *Huishi Suoyan* provide information about that. The skills were still practiced in modern times in Beijing, Nanjing as well as Zhejiang, Fujian and Guangdong Provinces.

**Fig. 93** A gold-foil-laid Buddha statue

But now, Nanjing is the main place to make gold foil. And Longtan in the district of Qixia in Nanjing is where gold foil making originated. It has been said among the people that the techniques and skills for making gold foil were invented by Ge Ruihong, who once competed with Lv Dongbin in hammering gold into foil when laying gold onto a Buddha statue (See Fig. 93). Ge outperformed Lv, and the techniques and skills then were passed down to later generations. Gold foil is made through many necessary processes.

Step 1 Melting and Casting. With respect to the percentage of gold contained, gold foil can be divided into that containing 98 % gold, that containing 88 % gold, etc. Take the 98 % gold foil. That is made from 98 % gold (containing 99.99 % gold thus being called four nines gold) and 2 % silver and copper. Melt those metals in a crucible, add borax into it to make slag, and then cast it into gold sticks with an iron mold.

Step 2 Making the blank and hammering it into slices. Hammer the gold sticks into plate blanks, with each 0.08 mm thick, pat them until they become as thin as required, and then cut the gold plates into square slices, with each side 16 cm long. During hamming the gold objects, heat them to avoid strain hardening. Take 120 gold slices obtained as one zuo (a unit of measurement).

Step 3 Making wicks. Cut the gold slice into wicks of 1 cm wide with a bamboo knife, of one zuo, 2048 gold wicks can be made.

Step 4 Preparing the gold Kaizi. Heat the 10 $\times$ 10 cm Wu Jin Zhi (a kind of paper) so that the gold wicks would unfold quickly when they are inserted into layers of Wu Jin Zhi.

Step 5 Inserting the gold wicks. Put the gold wicks into the layers of Wu Jin Zhi by fingers or with a pair of tweezers, and then package them with a piece of paper.

Step 6 Hammering the gold Kaizi. Hammer the package with gold wicks inserted into the layers of Wu Jin Zhi to make the unfolded gold wicks become thinner.

Step 7 Putting in the gold Kaizi. The thinned gold wicks between the layers of Wu Jin Zi are called Jin Kaizi. Since they are too light to be taken up, they need to be picked up with some goose feather with the aid of a blow from one's mouth. Then, put them into Wu Jin Zhi which is four times bigger in size. This is commonly called "Jiasheng."

Step 8 Heat Jiasheng Kaizi at a controlled temperature. Put Jiasheng Kaizi into the furnace and heat it for half an hour under a controlled temperature to remove strain hardening and prevent them from being affected of the outside temperature.

Step 9 Re-hammering. Keep on hammering the Jiasheng package. During the process, switch the place of the layers to prevent insufficient hammering. After this step of process, the gold foil will have extended to the pieces of $10 \times 10$ cm square, 0.12 μm thick.

Step 10 Taking out. Pick the gold foil with some goose feather and by aid of a blow from one's mouth to put it on a piece of paper on the table.

Step 11 Cutting gold foil. Cut the foil into squares with a bamboo knife.

Step 12 Packaging. Package the pieces of gold foil. Ten thousand pieces of $0.33 \times 0.33$ cm square only weigh 25 g.

Wu Jin Zhi is the key material for making gold foil, whose production requires sophisticated processes. It is made of the leaves of a kind of bamboo growing in the mountainous areas of Zhejiang Province. The leaves have to be buried underground for several years before they are taken out. Then, pound them with a stone hammer into soft pieces to make paper. Fire a tile with a bean oil lamp, and when there is carbon black formed on the tile, scrape the carbon black, and mix it with vegetable gum. Then, coat the made paper with the mixture, dry it and roll press it until it becomes flat and neat. The paper processed this way is appearance a very bright and smooth surface, which makes it easy for the gold slice inserted within to unfold. Today, the production of Wu Jin Zhi is still confined to Nanjing and Shaoxing, Zhejiang Province.

According to a survey, the well-known gold foil makers in the early Republic of China, included Han Xinggui, Yin Fucheng, and Yin Fujia; in the 1920s–1930s, Liu Xingguo, Guo Yifa, and Guo Yishun; and those who were born in the 1950s are Mei Zhenghua, Wu Tingkui, Gu Guangfu, and so on.

Since gold foil making with its variety of processes requires high and rigorous expertise and yet low-paying and heavy physical job, there are rarely young people today to learn to acquire those traditional techniques. The high efficiency and low cost of machine-making gold foil have brought an adverse effect on the traditional techniques and skills. In June of 2006, the techniques were put on the list of the first batch of our national intangible heritage. The Nanjing Gold Foil Factory will improve the measures taken to protect the old gold foil makers and cultivate the new generation ones, preserving and carrying forward those precious techniques and skills.

The remaining traditional metallurgical techniques also include those used to make the Husa Knife used by Achang people, the silver ornaments used by Miao people, the Beijng cloisonne, and the filament inlaid ornaments by Laofengxiang, Shanghai, but due to limited space, the present article will not deal with them.

Conclusion Chinese Traditional Metallurgical techniques in the Past and at Present

Although copper smelting and iron smelting emerged in China later than in the West, why the later comers surpass the formers, the reason is that in China there were a series of unique and original inventions like wooden supports in tunnels, copper sulfide ore smelting, separate casting, and pig iron smelting and casting (See Figs. 94, 95, 96 and 97)

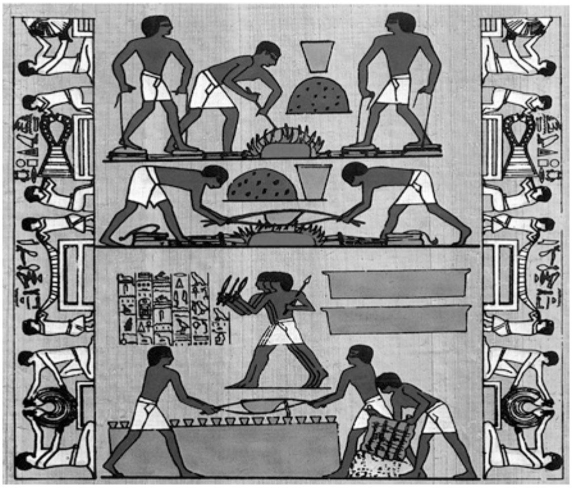
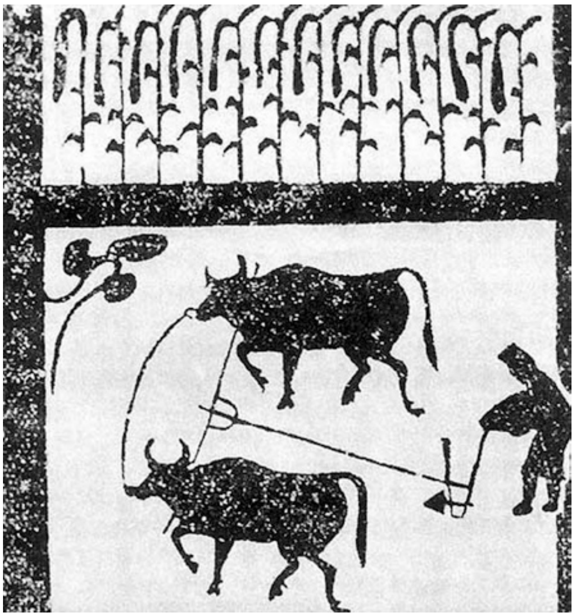


**Fig. 94** A site for bronze casting, a copy of the mural from Necropolis of Ancient Thebes, Egypt, in 1500 BC

**Fig. 95** A bronze bell produced in the Warring States period, excavated from Zeng Houyi's tomb at Suixian County, Hubei Province

**Fig. 96** A site for iron forging, a copy of the picture on a pottery bottle produced in Greece in about 500 BC

**Fig. 97** A picture of plowing with oxen, Han Dynasty Portrait Stone



China's brilliant achievements in metallurgic technology played a significant role in promoting the development of the Chinese nation and in improving the livelihood of her people. There were profound society reasons for why the traditional metallurgic technology had not been completely shifted to the system of modern metallurgic technologies in China. From the 5,000 year development of metallurgic technologies in China, we can see that major inventions were mostly made before Song and Yuan Dynasties and afterward, except for the techniques in copper smelting with cupric sulfate liquid (Dantongfa) and those in zinc smelting, mining and metallurgic industry largely had a quantitative rather than a qualitative development with the grow of population and the increase of daily demands. That was all because, from Song Dynasty on, the political and economic systems which were mainly based on the feudal dictatorship and landlord economy began to deteriorate, and there was lack of mental liberation and creative play. And it was clear that without the arrival of a new age, some new technologies could hardly appear. However, today, there are still many traditional metallurgic techniques with their inherent liveliness playing a very important role in the social production and people's daily life. Those traditional metallurgic techniques are our national treasure, and we need to cherish both the solid and the living legacies involved in them. Now, they are in crisis as to their academic tradition and discipline construction, so the central government and the departments concerned must pay close attention to that and take measures to enable those techniques to be sustainable development and invigoration.

## Author Biography

**Jueming Hua** was born on April 12, 1933, in Wuxi, Jiangsu Province. He went to work after graduation from high school in 1949. In 1958, he graduated from Mechanical Department of Qinghua University, and in 1967, he finished his graduation study by following Mr. Wang Zhenduo in Mining and Smelting History from Institute of History of Natural Science, the Chinese Academy of Sciences. From 1978 on, he worked in the same institute in turn as a Research Associate, Associate Professor, Professor, and Vice-director of the institute, and he resigned his post in the institute in 1993. Between 1988 and 1995, he went abroad as a visiting scholar in many universities like the State University of Australia, Teikyo University in Japan, the Metropolitan Museum of New York, and Technical University of Berlin. From 1993 to 2003, he was director of Institute of History of science and Technology and Ancient Literature Research in Qinghua University. During 1999 and 2000, he worked as a general designer of Zhonghua Hezhong (Chinese Bell). Right now, Mr. Hua is president of the Chinese Traditional Crafts Research Group, member of Intangible Cultural Heritage Protection Committee under Ministry of Culture, one of the experts with the State Bureau of Cultural Relics and Artifacts, and a part-time professor at many universities including Qinghua University, the Science and Technology University of China, Beijing University of Aeronautics and Astronautics, and Tongji University.

Since 1956, Mr. Hua has been engaged in researching on the history of science and technology. His research areas have included bronze smelting and casting in ancient times, iron and steel technology, and technological philosophy. His recent interest has been in the study and protection of the traditional crafts. So far, he has written eight monographs and more than 100 papers. The representative works of his include *Metallic Techniques in Ancient China, On History of Smelting and Casting in China, China's Science and Technology in Five Thousand Years, History of Science and Technology in China—Mechanical Volume*, and *Collected Works on Chinese Traditional Crafts—Masters in History*. He also participated in compiling other volumes of *Collected Works on Chinese Traditional Crafts, Collected Classical Works on Chinese Science and Technology, and Collection of Standards of Craftsmanship in Qing Dynasty*.

In 1983, he was awarded Second Prize of Scientific Achievements by Ministry of Mechanical Industry for his directing the study and restoration of the bell chimes in Xichuan's Chu Tomb. In 1984, he was awarded First Prize of Scientific Achievements by Ministry of Culture for his participating in and directing the study and restoration of Zenghouyi bell chimes. In 1993, his *Works of on History of Smelting and Casting in China and History of Development of World Metallurgy* (edited and translated) won the first and the second prizes from China Society for the History of Science and Technology, respectively, for writing excellent works. From 1997 to 2007, his *Collected Classical Works on Chinese Science and Technology, China's Science and Technology in Five Thousand Years and Collected Works on Chinese Traditional Crafts* (First Seven Volumes) in turn won a title of nominee in the fourth and fifth nationwide excellent books appraisal, the second prize for Scientific Progress, the second prize in the excellent science books appraisal, and an award in the first nationwide appraisal of excellent print works.

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