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Archaeologist-Led Studies on Bronze Casting in Ancient China: 1928–2000[1]

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Abstract: Chinese bronzes are both valuable archaeological remains and significant objects of study in the history of art and technology due to their unique style, complex functions, and technological sophistication. In 1928, the archaeological excavation in Anyang was regarded as the symbol of the establishment of the field of Chinese archaeology. By 2000, tens of thousands of bronzes, and some bronze foundries had been excavated and studied. In archaeologist-led studies, the issues involved are generic, and their scope is restricted, while in multi-disciplinary studies involving both archaeologists and historians of technology, the research is more specific, indicating that research effectiveness and scientific collaboration are closely correlated.
Keywords: bronze casting in China, archaeology, China

Ancient Chinese bronze wares are outstanding artistic works of masterful craftsmanship. Archaeology has revealed that collections of bronzes already existed early in the Shang dynasty, while inscriptions on bones or tortoise shells of the later Shang dynasty occasionally mention bronze casting. Historical records from the Warring States period (475–221 BCE) document the ritual functions of bronzes as symbols of royal power. The descriptions of bronze casting appearing in such records are largely theoretical, however, and cannot reflect the actual techniques of that time (Su and Wei 2017; Su 2016). In the Western Han dynasty (202 BCE–8 CE), the excavation of bronze wares was recorded many times, though the names were unrecognizable and the characters uninterpretable. In the Northern Song dynasty (960–1127 CE), with the rise of the Chinese Renaissance, it became common for the elite

[1] This paper is mainly based on part of "Ershi shiji dui xianqin qingtong liqi zhuzao jishu de yanjiu" 二十世纪对先秦青铜礼器铸造技术的研究 (On the casting techniques of ceremonial bronzes in the Pre-Qin period in the twentieth century) in *Quanwu toushang: quanwu boguguan qingtongqi toushe saomiao jiexi* 泉屋透赏：泉屋博古馆青铜器透射扫描解析 (The computed tomography at the Sumitomo Collection: The CT scanning and analyses of bronzes at the Sumitomo Collection), compiled by the Sumitomo Collection and Kyushu National Museum, 387–445 in 2015. It has been mainly translated by Lü Xin 吕昕 and copyedited by Lindy Divarci, Sarah Kuehne and John Moffett.

to collect bronzes and to identify their authenticity, producing illustrated works on the subject. However, no exploration was made on ancient bronze casting techniques until the mid-nineteenth century when Western learning, including natural history, archaeology, and art history, was gradually introduced into China. Chinese bronzes became popular collectors' items for wealthy Western businessmen and organizations, and were occasionally examined in laboratories. In the early twentieth century, as modern educational and scientific organizations became progressively established in China, some emerging disciplines were founded, one of which was archaeology. From the 1930s to the late 1970s, motivated by the urge to unravel the casting techniques of the bronzes they unearthed, archaeologists led the new research on bronze casting techniques (Su 2003, 26–35). This paper reviews the history of this field.

1 The initial phase: 1928–1950

In this phase, archaeologists gained their first access to relics such as unearthed bronze wares and casting molds, and became interested in their cultural and scientific value. They acquired a basic understanding of bronze-casting techniques by means of scientific analysis aided by invited scientists and metallurgists.

Research on the bronze casting technologies of ancient China was confused prior to the excavation of *Yinxu* 殷墟 (Yin ruins in Anyang, the archaeological remnants of the ancient city of Yin, the last capital of the Shang dynasty). According to popular opinion, the origin of such techniques was foreign (Creel 1935). Guo Moruo 郭沫若 advanced the view that metallurgy arose in South China earlier than it did in North China, and was then transferred to the Yellow River valley (Guo 1947, 256). His view may be regarded as a reflection of the scholarly tradition of annotations on the classics. Previously, a large number of extant bronze wares were reported to have been discovered in Anyang. Thus, the discovery of bronze objects and the remains of bronze casting during the excavations of the Yin ruins in Anyang caused great excitement among this first cohort of Chinese archaeologists. Molds, slags, charcoal, and bronze debris discovered in the ash pit in the Xiaotun 小屯 Village "not only indicated that there were bronze wares in the Shang dynasty, but also provided the proof that the ancients in the Shang dynasty had already mastered the technologies for bronze casting and it was in Xiaotun where they cast bronze wares" (Li 1930, 239–240). In seeking to understand these finds, Chinese archaeologists sought assistance in 1930 from Chinese chemists, who were only able to identify them as bronze due to the serious corrosion of the samples. As more relics were discovered in the spring of 1931, the archaeologists sent four samples for detailed analysis to Professor H. H. Carpenter (Imperial College London), who specialized in mining and was highly experienced in studying ancient Egyptian bronzes. Owing to their corroded state,

Carpenter conducted metallographic analyses of the specimens, demonstrating that the samples were of as-cast structure, and were bronzes containing 10.2%–20% tin (Carpenter 1933, 677–680; Li 1933a, 73–75). His research marks the beginning of Chinese archaeometallurgy. It exemplified the exploratory attitude toward intricate problems embodied by Li Chi 李濟 (1896–1979) and other Chinese archaeologists.

During the initial excavation of Anyang, Li Chi expected to discover more bronzes, thus "determining the true position of bronze casting at that time" (Li 1933a, 73). Careful consideration was given to bronze-casting processes, and comparisons were drawn between the Chinese techniques and those attested in ancient Egypt, Eurasia, and Europe (ibid., 73–104). Discussing the columns of *jue* 爵 vessels (Chinese ritual bronze tripod vessels or goblets used to serve or warm wine), he noted that the columns "were made out of the need for casting without any ritual meaning" (Li 1931, 476, 480). It was suggested that bronzes in early China could be dated back to the Xia dynasty based on the evidence from Anyang. The hollow legs of tripod vessels in Anyang were interpreted as "the marks in the initial stage of applying the bronze-casting technology to those vessels." Li realized the significance of bronze casting in Anyang (Li 1933b, 732) and prioritized "the casting procedures" in his general summaries and discussions of ceremonial bronzes there (Li 1976).

The plentiful remains excavated at Anyang spurred archaeologists to delve into how those bronze wares were produced. Liu Yuxia 劉嶼霞 believed that "the bronze wares excavated at Xiaotun were all cast with molds" (Liu 1933, 695), and explicitly stated that the hammer-forging technique was not employed. As the slags, malachite, charcoal and debris of helmet-shaped crucibles with slags adhered to them were found there, Liu deemed that the bronze had been smelted with crucibles, and that shaft furnaces were also utilized for bronze smelting (Li and Wan 1964, 681–696). Liu did not consider there to be an evident distinction between smelting and melting.

Shih Chang-ju 石璋如 (1902–2004), an archaeologist engaged in the early excavation of Anyang, evinced great interest in the technical study of bronzes and observed that casting molds were found in every excavation in Anyang (Shih 1947). He undertook an investigation into traditional crafts in Kunming to comprehend the basic procedures for the traditional lost-wax process and the traditional bronze-processing crafts (Chen et al. 2002, 207; Shih 1956).

2 Isolated archaeologists in Taiwan: 1951–1977

During the War of the Chinese People's Resistance against Japanese Aggression and the Chinese Civil War from 1937 to 1949, academic research on bronze casting came to a virtual standstill. In 1949 when the Nationalist government (Kuomintang) lost the Chinese mainland and relocated to Taiwan Province, a number of archaeologists

followed. They continued their research on the early bronze wares unearthed on the Chinese mainland and drew references from historical literature on traditional casting techniques. A systematic understanding of the composite molding of bronzes and other pertinent techniques was established, and the process of casting was tested and reproduced. Furthermore, they explored the relations between technology and art.

One member of this group, Shih Chang-ju, performed a preliminary and systematic study of the bronze-casting process in the Yin dynasty, including the after-casting processing and inlaying procedures (Shih 1955). His work was significant, but full of conjecture. In the report on the excavation of Yin, despite the research carried out on the bronze vessels there by Li Chi and Wan Chia-Pao 萬家保 (Shih 1970; idem 1973; idem 1980, 173–189, 215–228), Shih raised new questions about bronze casting (Shih 1980, 58–85).

According to Li Chi, "we should deal with the differences and evolution of the following six aspects separately: four various phenomena of a bronze ware—manufacturing, shape, ornamentation, inscriptions, and the other two deduced phenomena that were passed-down—functions and designations" (Li 1965, 8). In 1962, Wan Chia-Pao, a mechanical engineer, was recruited by the Institute of History and Philology, Academia Sinica. He collaborated with Li Chi in research on bronzes from Yin, particularly bronze-casting technologies. Their study involved 176 bronze vessels from Anyang, and more than 2000 fragments of clay molds and cores.

Research was conducted on 42 fragments of *gu* 觚 vessels (tall wine cup with no handles) and 26 clay molds used for *gu* casting excavated at Anyang. The objective was to "find out how the skillful craftsmen and artists in the Shang dynasty (sometimes referred to as Yin Shang) produced these exquisite bronze wares by inspecting the residual casting marks left on the bronze wares and the excavated bronze molds" (Li and Wan 1964, x, 1). Their research drew on studies of bronze-casting techniques in the prehistoric West and Egypt (Garland and Bannister 1927; Coghlan 1951). It also drew on the research of Orvar Karlbeck (1879–1967) and others (Yetts 1929; Karlbeck 1935; Barnard 1961), who consulted relevant works on traditional Chinese casting techniques, such as *Tiangong kaiwu* 天工開物 (The Exploitation of the Works of Nature) by Song Yingxing 宋應星.

Wan Chia-Pao meticulously examined what was left of the bronze *gu* vessels and found that most of the molds were bisected, and that only one of them was quartered and had traces of a horizontally divided mold. Among the bisected artifacts, the casting joint of R2017 did not coincide with the nose in the shape of a small flange of the beast-faced pattern in the abdomen, but instead was at its opposite position. He believed that the mold used for R2017 was an earlier type. Consequently, he did not believe that bronze vessels from Anyang were cast using the lost-wax process and

instead reconstructed the following casting procedure:

> Make a model out of the settled clay without adding other mixed materials, then place the model in the shade to dry slowly. → Carve patterns when the model is half dry. → Carve the intaglio characters and attach the characters cut in relief onto the model. → Dry the model beside a fire. → Make the outer molds (two or four pieces) from the model, and then add the decorations like circular patterns onto it. → Dry the mold beside a fire. → Scrape and pare the model into a core. → Assemble the outer molds around the core, and support them using two or four cross-shaped bronze sheets as spacers. → Melt the bronze. → Place the mold upside down, and pour the melted bronze to cast the bronze ware. (Liu 1933, 681–696)

With regard to the apertures in the legs of *gu* vessels, Wan Chia-Pao rejected the opinion of W. Perceval Yetts that the bronze chaplets, used in the lost-wax method to stabilize the core, formed the holes. On the contrary, Wan suggested that the holes were formed by the cross or rectangle-shaped bronze spacers used for supporting the clay core, believing the pieces later fell away from the core or disintegrated (Yetts 1929; Li and Wan 1964, 24–25). However, this explanation proved unconvincing.

Based on the findings of Wan Chia-Pao, Li Chi pursued further studies on the casting methods for the patterns of bronze *gu* vessels and classified them into 12 different types. On the basis of Wan's research on the manufacturing method of patterns of bronze *gu* vessels, the following five methods were identified by Li Chi (Li and Wan 1964, 69–114):

> 1. Simple incised mold design. These patterns consist of narrow and raised lines together with small circular decorations.
> 2. Composite model-mold design. These patterns comprise both narrow and broad raised lines, as well as bands of small circular decorations.
> 3. Engraving and appliqué on the model. In this case, there were already *di wen* 地紋 (intricate patterns that are filled in the gaps of the main ones) which are flush with the main patterns on one surface. These patterns are primarily formed on the model.
> 4. Relief on the model. There are patterns at different levels, which could be ascribed to the possibly applied method of piling up decorations on the model.
> 5. Deep incision on the model. This method was not commonly adopted, and the patterns are usually hollowed-out.

Notwithstanding the fact that the sequence of these methods had not been determined, it was found that this classification of manufacturing methods for similar patterns was not limited to *gu* vessels, but rather it represented "a highly common classification" (Li and Wan 1964) which was reminiscent of the five styles theory of Anyang bronze wares first proposed by Max Loehr (1903–1988) (Loehr, 1953).

Wan Chia-Pao and Li Chi conducted research on 42 bronze *jue* vessels and 63 clay

molds excavated in Anyang. They not only examined the casting joints of 39 bronze *jue* vessels, but also analyzed the burnishing and patching traces on these artifacts. Their research demonstrated that the most conspicuous casting joints appeared on the underside of the spout, the side of the handle, and the bottom of the knobs. Notable burnishing marks could be seen on the legs and the bottom of some bronze wares. The study of the molds showed that mortise and tenon joints were rarely used in composite molds. Parting agents, such as turpentine soot or red lead, could be found on the sides of the mold, and similar paint was applied to the ornamentation. The inside of the column was cast with the clay core as the mold in the abdomen (Li and Wan 1966, 8–16, 24).

In light of research on bronze *gu* and *jue* vessels, the Institute of History and Philology, Academia Sinica, with support from the Harvard-Yenching Institute, established a laboratory to undertake conservation research (Li and Wan 1970, iii). Sixteen bronze *jia* 斝 vessels (cauldron for warming wine) from Yin were studied. In order to investigate the casting method employed to manufacture the handle of R1115, cobalt-60 radiation was used for image analysis. Afterwards, Wan and Li explored the casting techniques of 23 bronze *ding* 鼎 vessels (prehistoric and ancient Chinese cauldrons, standing on legs, with a lid and two facing handles) from Anyang, and drew comparisons with other tripod vessels. Research by Rutherford J. Gettens exerted a significant impact on Wan (Gettens 1965). With the assistance of the Radiology Department of the College of Medicine, Taiwan University, Wan employed cobalt-60 radiation to reveal spacers. He recognized that "technical methods can account for the limited space of patterns on the bronze wares in the Shang dynasty." Although highly successful, the casting techniques using clay and section molds impeded the development of other ancient casting processes (Li and Wan 1970, 1–33).

The final bronze research by Wan and Li examined 53 bronze wares from Anyang belonging to other categories, concluding that "bronze wares of the same shape and structure were generally cast using the same or pertinent casting methods" (Li and Wan 1972, 9).

Although the research described above was undertaken by Li Chi and Wan Chia-Pao, the major technical work was done by Wan. Such a pattern of research has been replicated on the Chinese mainland since the 1980s, but with historians of metallurgy conducting the research. Wan's research orientation belonged to this category of research. He then went on to carry out studies on tripod artifacts, the *Maogong ding* vessel (the bronze tripod cauldron of Duke of Mao), the bronzes of the Spring and Autumn period excavated in Hui County, northern Henan Province, and the casting of inscriptions, as well as the metallographic analysis of bronze helmets from Anyang and the bronze industry there. The research methods established and accomplishments attained by Wan have become a mainstay of the scholarly literature in

this tradition (Su 2013, 105–125; idem 2015b).

3 Archaeologists on the Chinese mainland: 1950–1977

In contrast to their counterparts in Taiwan, most archaeologists on the Chinese mainland were committed to ongoing archaeological excavations and unearthed many new bronzes. A few of them also took an interest in bronze-casting techniques, including casting marks and composite molds, though their research was sometimes disturbed by political movements.

Owing to the enormous scale of civil engineering projects of the People's Republic of China, the relatively small number of qualified archaeologists were fully occupied with archaeological excavations. Among the few people investigating bronze casting was Guo Baojun 郭寶鈞 (1893–1971), who was also a member of the Anyang archaeological team. As early as 1932–1933, when Guo was investigating a grave of the Wei state dating to the Western Zhou period in Xin Village, Rui County, Henan Province, he became aware of the casting marks on bronzes (Guo 1936). During the 1950s when he was engaged in archaeological studies in Anyang and in northern Henan Province, he directed his attention to bronze casting, with an emphasis on composite molds (Guo 1951; idem 1964).

With regard to the small *ding* vessel (M6:24; 69 mm tall) excavated in Tomb no. 6 in Guwei Village, Hui County, Guo observed that "there were continuous normal and reverse patterns engraved around the neck. Patterns were carved on one ear, and the other one was without patterns after being soldered onto the body. Casting joints of the molds were absent from the bottom, and the ears, legs, and knobs were all soldered onto the bronze ware after being cast" (Institute of Archaeology, CASS 1956, 106). In addition, the small size was due to the fact that the ritual *ding* vessel was designed according to a model, and was cast using silversmith techniques. Unusually, the ears were cast on the body. As for the bronzes excavated at Tomb no.1 in Guwei Village, Guo documented the casting techniques as elaborately as possible.

With respect to the M1:9 chain bells with patterns of *panchi* 蟠螭 (a kind of snake-shaped dragon without horns) excavated at Shanbiaozhen, Ji County, Guo noted that "there are … seven small rectangular holes evenly-distributed on the top. All the holes are hollow, only one of which is found with burnt earth. … There are also two rectangular holes in the middle front, and eight in the front sides, which are all hollow. … *niuzhong* 鈕鐘 (dragon shaped tieback) and the body were cast in a single pour. … There are four evident symmetrical mold joints on the handle, top, front, and mouth. The patterns were stamped, and the stamp marks are noticeable" (Guo 1959, 6).

Guo investigated two of the seven *ding* vessels from Liulige 琉璃阁 in Hui County.

There were *panchi* patterns on the abdomen of M80:21, which were "stamped with an entire model" (Guo 1959, 56). On the other hand, the abdomen of the smaller *ding* vessel was "stamped with two thirds of the lower part of the model, and a third of the upper part was omitted" (ibid.). Guo pointed out that "this conformed to the practice that the craftsmen wanted to spare the time in sculpting a new model at that time" (ibid.). He also observed that these patterns were almost identical to those on the ears, abdomens, and legs of the *ding* vessels found in Lijialou 李家楼 in Xinzheng County, suggesting that "they could follow the tradition of the same craftsman" (ibid.). As for the *lei* 罍 vessel M60:35 (vessel for wine with a round body, a neck, a cover, and a handle on each side of the mouth), patterns were:

> Mainly repeatedly stamped by the *panhui* model with four intertwined *hui* patterns. The cover of the *lei* vessel was stamped with a band of *panhui* pattern, and a band of mountain-shaped pattern. The shoulders and abdomen were decorated with three bands of patterns, as well as two bands of downward patterns. All of them were in intaglio with thin lines, and the shoulders were embellished with round bubbles. (Guo 1959, 61)

These patterns are extremely similar to the *panchi* patterns on the *lei* vessel from Lijialou (Guo 1959, figs. on 57, 63, 60, 83).

Beginning in 1962, Guo focused his research on groups. He divided around 2000 bronzes (over 170 groups) into six stages. Systematic studies were primarily carried out on categories and combinations, shapes and casting techniques, patterns and inscriptions, and social background and application. He also defined six phases in the history of bronze casting under the Shang and Zhou dynasties: embryo, progress, advancement, combination, separate casting, and specialization. Guo was especially concerned with the combinations of casting joints and molds. In addition, he paid close attention to such details as the concave inner wall of *longhu zun* 龙虎尊 (a ritual vessel decorated with dragons and tigers) (Guo 1981, 122–128, 32, plates on 32).

Since the 1950s, the excavation of Niucun Village 牛村 in Houma County 侯马, Shanxi Province, has revealed a magnificent casting tradition during the Spring and Autumn period (Shanxi Provincial Institute of Archaeology 1993). Tens of thousands of bronze foundry remains inspired Zhang Wanzhong 张万钟, an archaeologist, to study bronze casting. It was Zhang who first recognized that the clay cores for the legs of *ding* vessels were equipped with dozens of core pins (Zhang 1962). For the ritual vessels and musical instruments, he pointed out the phenomenon of sectional models. He estimated that 3000 molds could be identified in the early excavations. If each mold had been employed ten times, that would have meant that 30,000 bronze tools had been cast, which implies the significant role that bronze played (Zhang 1987; idem 1996; idem 1997).

Guo Baojun's research was published posthumously in 1980 by Zou Heng 邹衡

and Xu Ziqiang 徐自强. His notes were treasured and circulated by subsequent scholars.[2] In addition, several other scholars, such as Rong Geng 容庚, Chen Mengjia 陈梦家 and Shi Zhilian 石志廉 (Su 2015a, 387–445), were also engaged in research on bronze casting to varying degrees.

4 Archaeologists on the Chinese mainland: 1977–2000

After the "Cultural Revolution" (1966–1976), archaeologists conducted scientific analyses on newly unearthed bronzes and at foundry sites; they carried out technical reconstructions and experiments and acquired a new understanding of bronze-casting techniques and their evolution. Meanwhile, from the 1980s, historians of metallurgy started to dominate studies on bronze manufacturing technology on the Chinese mainland. They proposed questions, organized research projects, and progressively constructed the landscape of ancient metallurgical technology in context.

After the "Cultural Revolution," only a few archaeologists engaged in studies on bronze-casting techniques. Of these, Li Jinghua 李京华 was the most prominent. With the abundant archaeological resources of the Central Plain, he devoted decades to explorations of ancient bronze and iron smelting and casting, publishing dozens of treatises (Li 1994b; idem 2003; idem 2006). As far as bronze casting was concerned, he carried out successive case studies on the excavated bronzes from Shang County, Zhengzhou, Henan Province, the Chu tomb in Xiasi, Xichuan County 淅川下寺, Henan Province, and the Chu tomb in Baoshan, Jingmen 荆门包山, Hubei Province. Many cases of separate casting were revealed, and explicit elucidation of the lost-wax casting techniques was provided through his studies on the bronze *jin* 禁 (bronze stand for ceremonial vessels) in Xiasi. Furthermore, research on the bronze wares from the Chu tomb in Baoshan demonstrated that in the Spring and Autumn period, bronze components were first separately cast, and then cast or soldered onto the body (Li 1991, 431–436; Li 1994a; Li 1999, 104–111; Li and Guo 1999, 112–124).

Since the 1980s, further research has been undertaken by Zhao Shigang 赵世纲, a leading excavator of the Chu tomb in Xiasi, Xichuan County (Spring and Autumn period) where a large quantity of high-caliber bronze wares of various types were discovered (Zhao 1991, 379–388).

The 1950s and 1960s witnessed significant discoveries at the foundry sites of the Yin ruins in Anyang (Institute of Archaeology, CASS 1987, 28–60, 65–69). One of the major excavators, Chen Zhida 陈志达, pursued systematic research on clay molds. In addition, discussions were held on the possible combinations of molds for the following bronze wares: large square *ding*, round *ding*, square *yi* 彝 (a kind of

[2] I am indebted to Professor Li Ling 李零 from Peking University for his advice.

sacrificial vessel in ancient China), *zhi* 觯 (a wide-necked vase, similar in shape to a *hu*, but with no handles), *gu*, *jue,* and human-faced masks. Chen investigated casting-on processes and the organization of production, thus rectifying mistakes made by his predecessors (Chen 1986).

Two bronze foundry sites were discovered in Nanguanwai 南关外 and Zijingshan 紫荆山 in Shang County, Zhengzhou, and a great many artifacts indicated that these workshops were primarily used for casting bronze tools. Pei Mingxiang 裴明相, one of the excavators, undertook the first research on bronze casting and investigated the composition of the molds used for the bronze vessels in Erligang 二里岗. Analyses were also made of bronzes from Dayangzhou 大洋洲, Xing'an County 新干, Jiangxi Province, where casting procedures were nearly identical to those used in Erligang, Zhengzhou. Studies were also undertaken on the technique of pre-casting copper patterns inlaid into molds on Chu bronzes (Pei 1989; idem 1992; idem 1994).

Thorough research on bronze-casting of the early Western Zhou period was carried out by Ye Wansong 叶万松, who investigated material from the foundry site in Beiyao 北窑, Luoyang. This covered a wide spectrum of techniques, including the manufacture of models, molds and cores, as well as composite molds and core pins, smelting and pouring. Ye was probably the first to discover the casting of joints and the stratification of cores. He also observed that mold design was conducted on models, and was the first to note that the jointing of composite molds was done with mud. He believed that during the early Western Zhou period, for all separate casting methods, accessories were cast first and were then cast onto the body of the mold (Ye 1984). It has been suggested that this workshop was operated by immigrants from Yin (the current Anyang), as suggested by the relation between the Beiyao tomb and the foundry site, and the inscriptions on the excavated bronzes. Hence, the processes employed were a direct technical inheritance from Yin (Chen and Xian 1995).

Tao Zhenggang 陶正刚, an archaeologist committed to studies on bronze-casting, led the excavation of the Eastern Zhou tombs found in Yangjuangou 羊圈沟 and Niujiapo 牛角坡 in Zhangzi County 长子县, Shanxi Province. He recognized that the handles and small beast-shaped knobs had been cast separately and then soldered onto the main body of the square-based *dou* 豆 (a flat, covered bowl on a long stem, a sacrificial vessel). In the tomb of the wife of an official (no. 7), traces of casting with three outer molds, casting joints and sprue marks were observed on *jian* 鑒 (a tall, broad bronze dish for water), *lie ding* 列鼎 (the prescribed set of *ding* based on the rank of the aristocrat for whom it was produced), *li* 鬲 (a boiling vessel), *zeng* 甑 (a steaming vessel, the upper part of *yan*), and *li* of *yan* 甗 (a bronze or pottery vessel composed of upper and lower parts). Tao observed that patterns on the molds were "commonly stamped with models, and the decorative designs were standardized into

patterns" (Shanxi Provincial Institute of Archaeology 1984). Furthermore, the *panchi* patterns and *panhui* patterns were mostly arranged in groups or blocks on *hu* 壺 (a wine vessel with a pear-shaped cross-section, and a body that swells and narrows at the neck), *ding*, and *dou* vessels. The patterns on the bronzes and

> those on the clay molds discovered in a bronze-casting workshop in Houma in the Jin state were almost identical. The clay molds in Houma were characterized with *panchi* with its tail in the mouth and *panfeng* 蟠鳳 (a coiled phoenix) clutching its wings. … Thus, it could be inferred that these bronze ceremonial vessels were all produced at the foundry sites in Houma in the Jin state". (ibid.)

Unfortunately, illustrations were not provided on how the handles and small beast-shaped knobs were soldered onto the body.

In 1988, the tomb for a *qing* 卿, a minister or a high official in ancient China named Zhao, was excavated in Jinsheng Village 金胜村, Taiyuan. This was the most complete tomb for a *qing* in the Jin state during the late Spring and Autumn period discovered to date, and contained 1402 bronzes representing a full range of casting techniques. Tao undertook studies on bronze-casting techniques and reconstructed the casting processes, based upon finds from the bronze-casting site in Houma. The accessories were mostly cast before being cast onto the main body. Molds were made with clay. Triangular supporting pins (namely the core pins) and spacers were widely utilized for composite molds, and the liquid metal was poured into the molds in an upside-down manner. Special attention was paid to pattern-making processes and the soldering of accessories (Tao 1996).

Tao was also committed to the exploration of the casting of patterns and inscriptions on bronzes in the Jin state. Based on models and molds from the foundry site in Houma, he adopted the position that the molds with patterns were gained by means of models, and these patterns were joined together in the molds. With regard to large bronzes, many molds with patterns were put together into a pattern unit. The point was made clear that the inscriptions on small bronze wares were cast through the method of embedding inscriptions into the mold pieces (Tao 1998).

Peng Shifan 彭适凡 also researched bronze-casting. He suggested that the stone molds found in large quantities in Jiangxi Province dated to the early Anyang period. These molds were soft, and made, for the most part, of red siltstone. A small proportion of them were hoary or cyan siltstone. They were primarily double molds, which were tied together when the molten metal was being poured into them. No stone molds were found for casting containers (Peng 1982, 42). The casting processes were consistent with those attested in the Central Plain, yet with some individual characteristics. Peng also proposed that South China might have been one of the birthplaces of Chinese bronze metallurgy (Peng et al. 1985, 72–80).

5 Concluding remarks

Scholars from various disciplines have, to varying degrees, made contributions to research on Chinese ancient bronzes. Much of the early research was based on epigraphy. With the spread of Western learning to China, and the establishment of archaeology there, studies on Chinese bronze-casting techniques were initiated. Archaeologists were the first to take the lead in carrying out this research, but since bronze casting involved specialized knowledge and training, they cooperated with technical experts and historians of metallurgy in bringing research on ancient bronze-casting processes to a new level.

The excavators of bronzes and foundry sites were most familiar with the state of the casting remains when excavated. Much relevant information would later disappear following restoration. Notwithstanding their recognition of the importance of bronze casting, there were neither avenues for archaeologists to acquire metallurgical knowledge, nor time or opportunities for them to pursue research on these issues. In the late 1970s, with the advent of "the Spring of Science," some archaeologists, recognizing that traditional typological studies were of only limited use, pinned their hopes upon research on casting processes (Gao 1981), and began discussing issues and collaborating with technical experts and specialists in historical metallurgy. Historians of metallurgical history shifted bronze-casting research to a stage dominated by metallurgical history (Su 2015a, 387–445).

In the 1980s, China's academic research became normalized, and the history of science and technology as a discipline was especially vibrant. In the sea of ancient Chinese documents, technological ones are rare and many techniques are not mentioned at all. Early technical research was reliant on relics and sites discovered during archaeological excavation and their studies and interpretation. Huge quantities of unearthed cultural relics expanded the research scope for scholars, thereby ushering studies on Chinese bronze casting into the era led by scholars of metallurgical history. During this era, which prospered until the end of the twentieth century, these scholars proposed questions, organized research projects, and step by step constructed the whole framework for ancient metallurgical technology. Their research was generally carried out in collaboration with archaeologists, thus boosting archaeometallurgy in China and advancing research on bronze-casting technology to a new level.

In the West, research on Chinese bronze wares is primarily conducted by art historians, who focus on the design and manufacturing of bronze, and explore the relations between style and technology. Furthermore, much effort is devoted to conserving bronzes by preservation experts whose approaches and results of scientific investigations are conducive to exploring bronze-casting techniques (Su 2015a, 395-404). Their research on the materials, techniques, styles, and conservation of bronzes has

generated much interest among Chinese scholars. Taking into account the functions of bronzes, they have delved into the production and circulation of ancient bronzes, the migration of casters, technological transmission, and the cost-effectiveness of casting.

Archaeology has undergone unceasing scientization and technicization. At the same time, in the realm of science and technology, ongoing research is being undertaken on ancient remains for the purpose of acquiring knowledge. The history of technology has placed increasing reliance on archaeological materials and is to a certain extent becoming "archaeologized." Future academic breakthroughs will only come from further and more intense interaction and integration of members of the different disciplines involved.

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References

Barnard, Noel. 1961. *Bronze Casting and Bronze Alloys in Ancient China*. Australia National University and Mounumeuta Serica.

Carpenter, Harold. 1933. "Preliminary Report on Chinese Bronzes." *Anyang Fajue Baogao* 安阳发掘报告 (The excavation report in Anyang) 4:677–680. Taipei: Institute of History and Philology, Academia Sinica.

Chen, Cungong 陈存恭, Chen Zhongyu 陈仲玉 and Chen Yude 任育德. 2002. "Shih Chang-ju xiansheng fangwenlu" 石璋如先生访问录 (Interview with Mr. Shih Chang-ju). In *Zhongyang yanjiuyuan jindaishi yanjiusuo koushulishi congshu* 中央研究院近代史研究所口述历史丛书. (Oral history series, Institute of Modern History, Academia Sinica), edited by Institute of Modern History, Academia Sinica, 80:207.

Chen, Xin 陈新 and Xian Ben 献本. 1995. "Luoyang beiyao M120 mu zhuren de shenfen ji xiangguan wenti" 洛阳北窑 M120 墓主人的身份及相关问题 (The identity and involved issues of the owner of tomb M120 in Beiyao, Luoyang). *Zhongyuan wenwu* 中原文物 (Cultural Relics of Central China) (2):61–65.

Chen, Zhida 陈志达. 1986. "Yinxu taofan jiqi xiangguan de wenti" 殷墟陶范及其相关的问题 (Clay molds in Anyang and pertinent issues). *Kaogu* 考古 (Archaeology) (3):269–277.

Coghlan, Herbert. 1951. "Notes on the prehistoric metallurgy of copper and bronze in the old world." Oxford: Pitt River Museum.

Creel, Herrlee. 1935. "On the Origins of the Manufacture and Decoration of Bronze in the Shang Period." *Monumenta Serica* 1:39–69.

Gao, Ming 高明. 1981. "Zhongyuan diqu Dongzhou shidai qingtong liqi yanjiu" 中原地区东周时代青铜礼器研究 (Studies on the ceremonial bronzes of the Central Plain in the Eastern Zhou dynasty). *Kaogu yu wenwu* 考古与文物 (Archaeology and Cultural Relics) 1(2):69.

Garland, Herbert and Charles Bannister. 1927. *Ancient Egypt Metallurgy*. London: C. Griffin.

Gettens, Rutherford. 1965. "Joining Method in the Fabrication of Ancient Chinese Bronze Ceremonial Vessels." *Application of Science in Examination of Works of Art*: 205–217. Proceedings of Seminar: Sept. 7–16, conducted by the Research Laboratory. Boston: Museum of Fine Arts.

Guo, Baojun 郭寶鈞. 1936. "Junxian Xincun gucanmu zhi qingli" 浚縣辛村古殘墓之清理 (The recovery of the ancient residual tombs in Xin Village, Jun County). *Tianye kaogu baogao diyice* 田野考古報告第一冊 (Report on field archaeology) vol. 1:186–187.

Guo, Baojun. 1951. "Yijiuwuling nian chun Yinxu fajue baogao" 一九五〇年春殷墟發掘報告 (Excavation report of Anyang in the spring of 1950). *Zhongguo kaogu xuebao* 中國考古學報 (*Acta Archaeologica Sinica*) (5):1–61.

Guo, Baojun. 1959. *Shanbiaozhen yu Liulige* 山彪鎮与琉璃阁 (Shanbiaozhen and Liulige). 6, 56, 61, images on 57, 63, 60, 83. Beijing: Science Press.

Guo, Baojun. 1964. *Ruixian Xincun* 濬县辛村 (Xin Village, Rui County). Beijing: Science Press.

Guo, Baojun. 1981. *Shangzhou tongqi qun zonghe yanjiu* 商周铜器群综合研究 (Comprehensive research on the bronze group in the Shang and Zhou dynasties): 122–128, 32, image on 32. Beijing: Cultural Relics Press.

Guo, Moruo 郭沫若. 1947. *Qingtong shidai* 青銅時代 (The Bronze Age): 256. Shanghai: Qunyi Press.

Institute of Archaeology, Chinese Academy of Social Sciences. 1956. *Huixian fajue baogao* 輝縣發掘報告 (Excavation report in Hui County): 106. Beijing: Science Press.

Institute of Archaeology, Chinese Academy of Social Sciences. 1987. *Yinxu fajue baogao 1958–1961* 殷墟发掘报告 1958–1961 (Excavation report in Anyang during 1958–1961): 28–60, 65–69. Beijing: Cultural Relics Press.

Karlbeck, Orvar. 1935. "Anyang Mould." *Bulletin of the Museum of Far Eastern Antiquities* 7:39–60.

Li, Chi 李濟. 1930. "Minguo shiba nian qiuji fajue Yinxu zhi jinguo jiqi zhongyao faxian" 民國十八年秋季發掘殷墟之經過及其重要發現 (The process of excavation in Anyang and the significant discoveries in the autumn of the eighteenth year in the Minguo Calendar). *Anyang Fajue Baogao* 安陽發掘報告 (The excavation report in Anyang) vol. 2:239–240.

Li, Chi. 1931. "Fushen zang" 俯身葬 (Overturned burial). *Anyang fajue baogao* 安陽發掘報告 (The excavation report in Anyang) vol. 3:476, 480.

Li, Chi. 1933a. "Yinxu tongqi wuzhong jiqi xiangguan zhi wenti" 殷墟銅器五種及其相關之問題 (Five kinds of bronze wares in Anyang and pertinent issues). In *Qingzhu Cai Yuanpei xiansheng liushiwusui lunwenji* 慶祝蔡元培先生六十五歲論文集 (Collected papers for commemorating the sixty-fifth birthday of Mr. Cai Yuanpei): 73–104. Taipei: Institute of History and Philology, Academia Sinica.

Li, Chi. 1933b. Additional notes. *Anyang fajue baogao* 安陽發掘報告 (The excavation report in Anyang) vol. 4:732.

Li, Chi and Wan Chia-Pao 萬家保. 1964. "Yinxu chutu qingtong guxingqi zhi yanjiu" 殷墟出土青銅觚形器之研究 (Studies on the *gu*-shaped bronze wares unearthed from Anyang). *Guqiwu yanjiu zhuankan diyiben* 古器物研究專刊第一本 (Studies on antiquities, vol. 1): x, 1, 24–25, 69–114. Taipei: Institute of History and Philology, Academia Sinica.

Li, Chi and Wan Chia-Pao. 1966. "Yinxu chutu qingtong dingxingqi zhi yanjiu" 殷墟出土青銅鼎

形器之研究 (Studies on the *ding*-shaped bronze wares unearthed from Anyang). *Guqiwu Yanjiu zhuankan dierben* 古器物研究專刊第二本 (Studies on antiquities, vol. 2): 8–16, 24. Taipei: Institute of History and Philology, Academia Sinica.

Li, Chi and Wan Chia-Pao. 1970. "Yinxu chutu qingtong dingxingqi zhi yanjiu" 殷墟出土青銅鼎形器之研究 (Studies on the *ding*-shaped bronze wares unearthed from Anyang). *Guqiwu Yanjiu zhuankan disiben* 古器物研究專刊第四本 (Studies on antiquities, vol. 4): iii, 1–33. Taipei: Institute of History and Philology, Academia Sinica.

Li, Chi and Wan Chia-Pao. 1972. "Yinxu chutu wushisan jian qingtong rongqi zhi yanjiu" 殷墟出土五十三件青銅容器之研究 (Studies on fifty-three bronze wares unearthed from Anyang). *Guqiwu yanjiu zhuankan diwuben* 古器物研究專刊第五本 (Studies on antiquities, vol. 5): 9. Taipei: Institute of History and Philology, Academia Sinica.

Li, Chi. 1965. "Ruhe yanjiu Zhongguo qingtongqi" 如何研究中國青銅器 (On how to study Chinese bronze wares). *Gugong jikan* 故宮季刊 (National Palace Museum Quarterly) 1(1):8.

Li, Chi. 1976. "Yinxu chutu qingtongqi zhi zongjiantao" 殷墟出土青銅禮器之總檢討 (General summaries and discussions of ceremonial bronzes unearthed in Anyang). *Zhongyang yanjiuyuan lishi yuyan yanjiusuo jikan* 中央研究院历史语言研究所集刊 (Journal of Institute of History and Philology, Academia Sinica) 47(4):788.

Li, Jinghua 李京华. 1991. "Baoshan Chumu qingtongqi zhizao jishu de chubu kaocha" 包山楚墓青铜器制造技术的初步考察 (A preliminary study on the manufacturing techniques of the bronzes in the Chu-tomb in Baoshan). In *Baoshan Chumu* 包山楚墓 (The Chu-tomb in Baoshan), edited by the Railway Archaeological Team in Jingsha, Hubei 湖北荆沙铁路考古队, 431–436. Beijing: Cultural Relics Press.

Li, Jinghua. 1994a. "Xichuan Chunqiu Chumu tongjin shila zhuzaofa de gongyi tantao" 淅川春秋楚墓铜禁失蜡铸造法的工艺探讨 (Discussion on the lost-wax process of bronze *jin* unearthed from the Chu-tomb in Xichuan in the Spring and Autumn period). *Wenwu baohu yu kaogu kexue* 文物保护与考古科学 (Sciences of Conservation and Archaeology) 6(1):39–45.

Li, Jinghua. 1994b. *Zhongyuan gudai yejin jishu yanjiu* 中原古代冶金技术研究 (Studies on ancient metallurgical technologies of the Central Plain). Zhengzhou: Zhongzhou Ancient Books Publishing House.

Li, Jinghua. 1999. "Zhengzhou Shangdai dafangding pinzhu jishu shixi" 郑州商代大方鼎拼铸技术试析 (The joint-casting skill of square *ding* from Zhengzhou in the Shang dynasty). In *Zhengzhou Shangdai tongqi jiaocang* 郑州商代铜器窖藏 (Cellared bronze wares in the Shang dynasty in Zhengzhou), compiled by Henan Provincial Institute of Cultural Relics and Archaeology and Zhengzhou Institute of Cultural Relics and Archaeology, 104–111. Zhengzhou: Zhongzhou Ancient Books Publishing House.

Li, Jinghua and Guo Yihong 郭移洪. 1999. "Zhengzhou Shangdai jiaocang tongfangding pinzhu jishu shixi" 郑州商代窖藏铜方鼎拼铸技术试析 (On the joint-casting processes of the cellared bronze square *ding* from Zhengzhou in the Shang dynasty). In *Zhengzhou Shangdai tongqi jiaocang* 郑州商代铜器窖藏 (Cellared bronze wares in the Shang dynasty in Zhengzhou), compiled by Henan Provincial Institute of Cultural Relics and Archaeology and Zhengzhou Institute of Cultural Relics and Archaeology, 112–124. Zhengzhou: Zhongzhou Ancient Books Publishing House.

Li, Jinghua. 2003. *Zhongyuan gudai yejin jishu* 中原古代冶金技术 (Ancient metallurgical technologies of the Central Plain) Part 2. Zhengzhou: Zhongzhou Ancient Books Publishing House.

Li, Jinghua. 2006. *Li Jinghua wenwu kaogu lunji* 李京华文物考古论集 (Collection of Li Jinghua's archaeological studies on cultural relics). Zhengzhou: Zhongzhou Ancient Books Publishing House.

Liu, Yuxia 劉嶼霞. 1933. "Yindai yetongshu yanjiu" 殷代冶銅術研究 (Research on the bronze-casting techniques in the Yin dynasty). *Anyang fajue baogao* 安陽發掘報告 (The excavation report in Anyang) vol. 4:681–696.

Loehr, Max. 1953. "The bronze style of Anyang Period." In *Archives of the Chinese Art Society of America* 7:42–53.

Pei, Mingxiang 裴明相. 1989. "Zhengzhou Shangdai qingtongqi zhuzao shulüe" 郑州商代青铜器铸造述略 (A brief account of bronze casting in the Shang dynasty). *Zhongyuan wenwu* (3): 90–96.

Pei, Mingxiang. 1992. "Lüelun Chuguo de hongtong zhuxiang gongyi" 略论楚国的红铜铸镶工艺 (On the process of pre-casting red copper patterns inlaid into molds in the Chu state). *Zhongyuan wenwu* (2):47–50.

Pei, Mingxiang. 1994. "Jiangxi Shangdai tongqi yu Erligang Shang wenhua" 江西商代铜器与二里冈商文化 (The bronze wares in Jiangxi in the Shang dynasty and the culture of the Shang dynasty in Erligang). *Nanfang wenwu* 南方文物 (Cultural Relics in Southern China) (2):23–29.

Peng, Shifan 彭适凡. 1982. "Jiangxi Shangzhou qingtongqi zhuzao jishu" 江西商周青铜器铸造技术 (The bronze casting technology of Jiangxi Province in Shang and Zhou dynasties). In *Kejishi wenji* 科技史文集 (The Anthology of science of history and technology) vol. 9:42. Shanghai: Shanghai Scientific & Technical Publishers.

Peng, Shifan, Hua Jueming 华觉明 and Li Zhongda 李仲达. 1985. "Jiangxi diqu zaoqi tongqi yezhu jishu de jige wenti" 江西地区早期铜器冶铸技术的几个问题 (Several issues on early bronze casting technology in Jiangxi Province). In *Zhongguo kaogu xuehui disici nianhui lunwenji* 1983 中国考古学会第四次年会论文集·1983 (Collected papers of the 4th Annual Conference of the China Archaeological Society in 1983): 72–80. Beijing: Cultural Relics Press.

Shanxi Provincial Institute of Archaeology. 1984. "Shanxi Zhangzixian Dongzhou mu" 山西长子县东周墓 (The Eastern Zhou tomb in Zhangzi County in Shanxi Province). *Kaogu xuebao* 考古学报 (Acta Archaeologica Sinica) (4):503–529.

Shanxi Provincial Institute of Archaeology. 1993. *Houma zhutong yizhi* 侯马铸铜遗址 (Bronze foundry sites in Houma). Beijing: Cultural Relics Press.

Shih, Chang-ju 石璋如. 1947. "Yinxu zuijin zhi zhongyao faxian, fulun Xiaotun diceng" 殷墟最近之重要發現，附論小屯地層 (The significant discoveries in Anyang, with the appendix on Xiaotun's strata). *Zhongguo kaogu xuebao* (2):39.

Shih, Chang-ju. 1955. "Yindai de zhutong gongyi" 殷代的鑄銅工藝 (Bronze-casting processes in the Yin dynasty). *Zhongyang yanjiuyuan lishi yuyan yanjiusuo jikan* 中央研究院歷史語言研究所集刊 (Journal of Institute of History and Philology, Academia Sinica) vol. 26:95–129.

Shih, Chang-ju. 1956. "Ji Kunming de sizhong tongye" 記昆明的四種銅業 (On four kinds of copper industries in Kunming). *Zhongyang yanjiuyuan yuankan* 中央研究院院刊 (Journal of

Academia Sinica) vol. 3:227–237.

Shih, Chang-ju. 1970. "Yinxu muzang zhi yi beizu muzang shang" 殷墟墓葬之一・北組墓葬上 (Tombs in Anyang [chapter 1]: The north tomb group [section 1]). In *Xiaotun diyiben yizhi de faxian yu fajue bingbian* 小屯第一本・遺址的發現與發掘丙編 (Xiaotun [series 1]: The discovery and excavation of the site [part 3]): 379–394. Taipei: Institute of History and Philology, Academia Sinica.

Shih, Chang-ju. 1973. "Yinxu muzang zhi san nanzu muzang fu beizu mu buyi" 殷墟墓葬之三・南組墓葬附北組墓補遺 (Tombs in Anyang [chapter 3]: The south tomb group, with the addendum of the north tomb group). In *Xiaotun diyiben yizhi de faxian yu fajue bingbian* 小屯第一本・遺址的發現與發掘丙編 (Xiaotun [series 1]: The discovery and excavation of the site [part 3]): 24–45. Taipei: Institute of History and Philology, Academia Sinica.

Shih, Chang-ju. 1980. "Yinxu muzang zhi wu bingqu muzang shang" 殷墟墓葬之五・丙區墓葬上 (Tombs in Anyang [chapter 5]: The third tomb area [section 1]). In *Xiaotun diyiben yizhi de faxian yu fajue bingbian* 小屯第一本・遺址的發現與發掘丙編 (Xiaotun [series 1]: The discovery and excavation of the site [part 3]): 58–85, 173–189, 215–228.

Su, Rongyu 苏荣誉. 2003. "A History of the Study of Bronze Casting in Ancient China." In *Scientific Research in the Field of Ancient Art*. Proceedings of the First Forbes Symposium at the Freer Gallery of Art, edited by Paul Jett, 26–35. London: Archetype Publications Ltd.

Su, Rongyu. 2013. "Lun Wan Chia-Pao xiansheng dui Yinxu qingtongqi zhuzao jishu de yanjiu" 论万家保先生对殷墟青铜器铸造技术的研究 (On Mr. Wan Chia-Pao's research of bronze-casting processes in Anyang). In *Jishu chuanbo yu wenhua yichan* 技术传播与文化遗产 (Technological transmission and cultural heritage), edited by Jiang Zhenhuan 姜振寰, 105–125. Beijing: China Science and Technology Press.

Su, Rongyu. 2015a. "Ershi shiji dui Xianqin qingtong liqi zhuzao jishu de yanjiu" 二十世纪对先秦青铜礼器铸造技术的研究 (On the casting techniques of ceremonial bronzes in the Pre-Qin period in the twentieth century). In *Quanwu toushang: quanwu boguguan qingtongqi toushe saomiao jiexi* 泉屋透赏：泉屋博古馆青铜器透射扫描解析 (The computed tomography at the Sumitomo Collection: The CT Scanning and analyses of bronzes at the Sumitomo Collection), compiled by the Sumitomo Collection and Kyushu National Museum, 387–445. Beijing: Science Press.

Su, Rongyu. 2015b. "Wan Chia-Pao xiansheng yanjiu yinxu qingtongqi zhuzao jishu guankui"万家保先生研究殷墟青铜器铸造技术管窥 (A glimpse of Mr. Wan Chia-Pao's research on bronze-casting processes in Anyang). *Zhonghua Yishu Jianshang* 中华艺术鉴赏 (China Art Appreciation) (9): 92–103.

Su, Rongyu. 2016. "Kaogong ji 'liu ji' zai yanjiu" 《考工记》"六齐"再研究 (Reconducted research on "liu ji" in *The Artificers' Record*). In *Wenben tuxiang jiyi* 文本•图像•记忆 (Text, image and memory), edited by Zhu Yuanqing 朱渊清 and Wang Tao 汪涛, 175–192. Shanghai: East China Normal University Press.

Su, Rongyu and Wei Qiuping 魏秋萍. 2017. "Gu qiwu de zhizuo jishu: fei wenben wenxian de zhishi goujian yi Yinxu qingtong ding zhizuo weili" 古器物的制作技术：非文本文献的知识构建——以殷墟青铜鼎制作为例 (Manufacturing techniques of ancient artifacts: knowledge construction of non-textual literature — a case study of the production of bronze *ding* in ruins

of Yin). In *Kexue jishu yu shehui fazhan yanjiu* 科学技术与社会发展研究 (Research on science and technology and social development), edited by Zhang Tao 张涛, Wu Li 武力 and Li Yi 李毅, 52–77. Beijing: Tsinghua University Press.

Tao, Zhenggang 陶正刚. 1996. "Taiyuan Jinguo Zhaoqingmu qingtongqi gongyi yu yishu tese" 太原晋国赵卿墓青铜器工艺与艺术特色 (Casting processes and artistic characteristics of the bronzes unearthed from the tomb of the official surnamed Zhao in the Jin state in Taiyuan). In *Taiyuan Jinguo Zhaoqingmu* 太原晋国赵卿墓 (The tomb of the official surnamed Zhao in the Jin state in Taiyuan), compiled by Tao Zhenggang, Hou Yi 侯毅 and Qu Chuanfu 渠川福, 295–302. Beijing: Cultural Relics Press.

Tao, Zhenggang. 1998. "Jinguo qingtongqi zhuzao gongyi zhong de liangge wenti" 晋国青铜器铸造工艺中的两个问题 (Two issues in the bronze casting processes of the Jin state). *Wenwu* 文物 (Cultural Relics) (11):71–76.

Ye, Wansong 叶万松. 1984. "Woguo Xizhou qianqi qingtong zhuzao gongyi zhi yanjiu" 我国西周前期青铜铸造工艺之研究 (Research on bronze casting processes in the early Western Zhou dynasty). *Kaogu* (7):656–663.

Yetts, Perceval. 1929. "The George Eumorfopoulos Collection." *Catalogue of the Chinese and Corean Bronzes* 1:37.

Zhang, Wanzhong 张万钟. 1962. "Houma Dongzhou taofan de zaoxing gongyi" 侯马东周陶范的造型工艺 (The molding processes of clay molds in Houma in the Eastern Zhou dynasty). *Wenwu* (4–5):37–42.

Zhang, Wanzhong. 1987. "Nixing zhuzao fazhanshi" 泥型铸造发展史 (The history of clay mold casting). *Zhongguo lishi bowuguan guankan* 中国历史博物馆馆刊 (Publication of the History Museum of China): 32–34.

Zhang, Wanzhong. 1996. "Dongzhou shiqi nixing zhuzao de xin chengjiu: cong Houma chutu de taofan shitan fenkuaimu de zaoxing gongyi" 东周时期泥型铸造的新成就：从侯马出土的陶范试探分块模的造型工艺 (New accomplishments of clay mold casting in the Eastern Zhou dynasty: On the molding processes of separate molds based on the unearthed clay molds in Houma). *Zhongguo lishi bowuguan guankan* (1):25–30.

Zhang, Wanzhong. 1997. "Cong Houma chutu de gongju fan shilun qingtong nongju de zhuzao yu shiyong" 从侯马出土的工具范试论青铜农具的铸造与使用 (On the casting and application of bronze farm implements based on the unearthed tool molds in Houma). *Zhongguo lishi bowuguan guankan* (1):61.

Zhao, Shigang 赵世纲. 1991. "Xichuan Xiasi Chunqiu Chumu qingtongqi de zhuzao gongyi" 淅川下寺春秋楚墓青铜器铸造工艺 (The bronze casting techniques in Chu-tomb in the Spring and Autumn period in Xiasi, Xichuan). In *Xichuan Xiasi Chumu* 淅川下寺楚墓 (Chu-Tomb in Xiasi, Xichuan), edited by Henan Provincial Institute of Cultural Relics et al., 379–388. Beijing: Cultural Relics Press.