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Bronze casting techniques of the Erlitou Culture period

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Abstract

Erlitou is an important site of pre-Qin cultural remains at which the earliest bronze casting workshops in China known to date were discovered. Based on the observation and analyses of the bronzes, pottery molds and foundry ladles, this paper discusses the bronze casting techniques of the Erlitou Site. The most noticeable characteristic of the bronzes unearthed at Erlitou is that their walls are thin but even, showing that at the time of the Erlitou Culture, bronze casting techniques had reached a rather high level: rational mold division and precise mold positioning techniques had appeared; the mold designs of some bronzes with simple shapes had fallen into patterns that saw continued use throughout the Bronze Age; the mold designs of bronzes with complex shapes (especially *jue*-cups) were not stereotyped and unchanging; and defects occurring in the casting process were corrected with a burning-on technique which was the incipient form of the cast-joining technique, an extremely important feature of pottery mold casting. The material components of the pottery molds and their processing techniques; the pottery mold positioning technique; and the pouring cups and foundry ladles found at Erlitou prove that the Erlitou Culture was capable of casting small bronze vessels with thin and even walls. These technical achievements reflect the fact that in the early Bronze Age, sophisticated pottery mold casting techniques existed in China, laying a firm technical foundation for the high development of bronze casting techniques during the Bronze Age.

Keywords: Bronzes–China–to 221 BC; Erlitou Site (Yanshi City, Henan); forging industry; foundry ladles; molds and molding (founding)–history

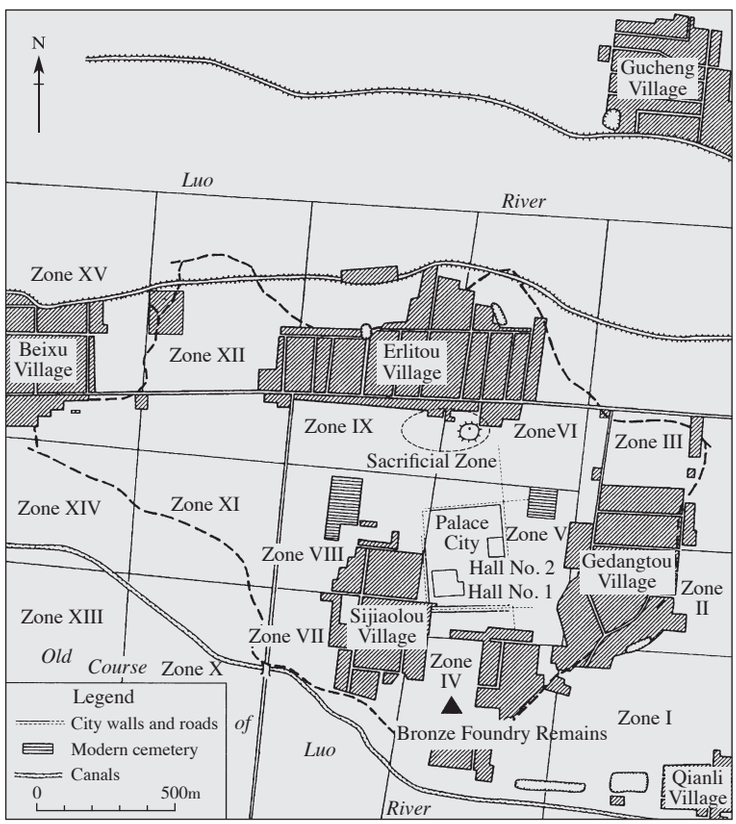

Figure 1 The location of the Erlitou foundry remains.

The analyses of the bronze casting techniques through the observation of the bronze products unearthed in Erlitou Site

The remains of the earliest bronze foundry known to date in China were discovered at Erlitou Site (Figure 1). The foundry remains lie mainly in Zone IV of the site, while bronze artifacts have been discovered in Zones III, IV, and V, covering a total area of over 1ha. Bronze casting workshop remains dating to Phases II through IV have already been excavated. The surrounding environment contained significant quantities of clay molds, crucibles, furnace walls, copper slag, and charcoals, as well as some small bronze items and a small number of large bronzes.

Bronzes are one of the main artifact types found at Erlitou Site. Discoveries have included ritual vessels, tools, military implements, etc. Among these were *jue*-cups, *jia*-tripods, *ding*-tripods, bells, plaques, *ge*-dagger axes, *yue*-battle axes, arrowheads, knives, awls, chisels, adzes, saws, fishhooks,

and copper spheres, as well as various fragmentary items.

The bronze casting techniques of the Erlitou Site are representative of the early Chinese Bronze Age; they shaped the characteristic features of Chinese bronze casting, and as such, they are a key component of the research into the early history of ancient Chinese metallurgy. This article carries out such an investigation through an examination and analysis of bronze items, molds, and foundry ladles discovered at the Erlitou Site, as well as of the casting techniques with which they were associated.

Smelted copper slag has already been unearthed from Phase I of Erlitou Culture. Phase II through IV have all produced clay molds for bronze casting, clarifying that the bronze items of the Erlitou Site were formed through casting methods employing such molds. This process inevitably leaves greater or lesser traces of the mold junction points on the surface of the resultant bronzes – the so-called *fanxian* ("mold lines", i.e. casting fins). An examination of these casting fins, as well as of the traces of the pouring cups, can support research into the process of mold assembly as conducted in the Erlitou bronze workshop.

1. The analyses and discussions of the *jue*-cups, bells, knives, and a bronze fragment.

Jue-cups: Examination revealed that the *jue*-cups unearthed at Erlitou were all cast fully formed. The casting process employed two different methods of mold division:

In the first method, the outer mold was produced without a parting of upper and lower sections, as with *jue*-cup 84YLVIT4M6:5. The lower portion of the grip reaches to the point of contact between one foot and the belly, and the mold cavity of the grip was partly linked with that of the feet. This shows that the outer mold was not divided into upper and lower portions. The *jue* was instead produced using 2–3 outer mold segments that extended from the mouth of the vessel to the tips of the feet; a clay core for the belly of the vessel; a clay core for the grips; and a base mold with cavities of the three feet. The position of the pouring aperture is unclear (Figure 2).

In the second method, the outer mold was parted into upper and lower sections with the boundary at the bottom of the vessel belly, as with *jue*-cup 84YLVIM11:1. Horizontal traces of the parting line between mold sections are visible on the walls of the vessel belly at the points where they meet the flat bottom. The casting of the vessel was thus accomplished using two separate sections of outer mold, an upper and a lower, with the bottom of the vessel belly as the boundary between the two. The upper section was symmetrical along the midline of the spout and tail; it employed 2–3 outer mold segments, along with a clay core for the belly and another for the grip, to produce the belly section of the vessel. The lower section produced the three legs of the vessel using 2–3 outer mold segments and a base mold containing cavities in the shape of the legs. The upper and lower sections were combined to form the overall shape of the *jue*-cup. The position of the pouring aperture is unclear (Figure 3). Among seven *jue*-cups found in Erlitou, most were cast using the first method; only one was cast using the second.

Jue-cup 80YLIIIM2:1 bears traces of a repair casting on the base of its belly. The repaired portion is irregular but basically symmetrical between inside and out. A small, oval protrusion is present on the outer bottom of the repaired portion, indicating the position of the pouring aperture for the repair casting (Figure 4).

Bells: Casting fins from the junction of the outer mold segments are visible on the two sides of the resonator of this bell with almond-shaped cross-section, indicating that the body of the bell was cast using two arched outer mold segments and one clay core. An attached ear appears on one side of the casting line, showing that the entire cavity for shaping the ear was located on only one of the outer mold segments. No parting lines have yet been discovered on the crown of the bell; the crown section had its own separate outer mold segment containing a space for the bridge-shaped suspension ring atop the bell. The casting cavity for the crown of the bell and the suspension ring was formed by the crown mold segment and the casting core for the resonator box. Overall, the casting

Figure 2 Bronze *jue*-cup (84YLVIT4M6:5) unearthed in Erlitou Site.

Figure 3 Bronze *jue*-cup (84YLVIM11:1) unearthed in Erlitou Site.

of the bell was thus accomplished using two arched outer mold segments, one crown mold segment, and one core. No trace of the pouring aperture has been found on the bell; however, based on the item's shape, one may guess that the aperture was located in the ear adorning one side of the bell or near the rim of the resonator cavity (Figure 5).

Knife: Bronze knife 80YLIIIM2:3 had one casting core for the inside of the hilt; some casting flash remains in the openwork portions. The casting was carried out with two symmetrical outer mold segments divided longitudinally along the central axis of the knife blade and one core. Traces of the pouring aperture, approximately 1.5cm long, are visible on the end of the ring-shaped pommel on the hilt. This method of placing the pouring aperture saw continuous use in the casting of this sort of tools and weapons (Figure 6).

Bronze fragment: This fragment appears to have belonged to the handle of an implement. Its outer surface bears a casting fin. The fragment contains a hole in the shape of a square cone, smaller on the outside and larger on the inside; this hole was left by an integrated chaplet used with the core, showing that the practice of integrating chaplets with the casting core to fix it in place was already employed by the Erlitou period. The fragment was cast using two outer mold segments and one clay core with integrated support (Figure 7).

2. Survey of the thickness of bronze vessel walls. The thicknesses of the walls of three *jue*-cups and one *he*-pitcher were measured,

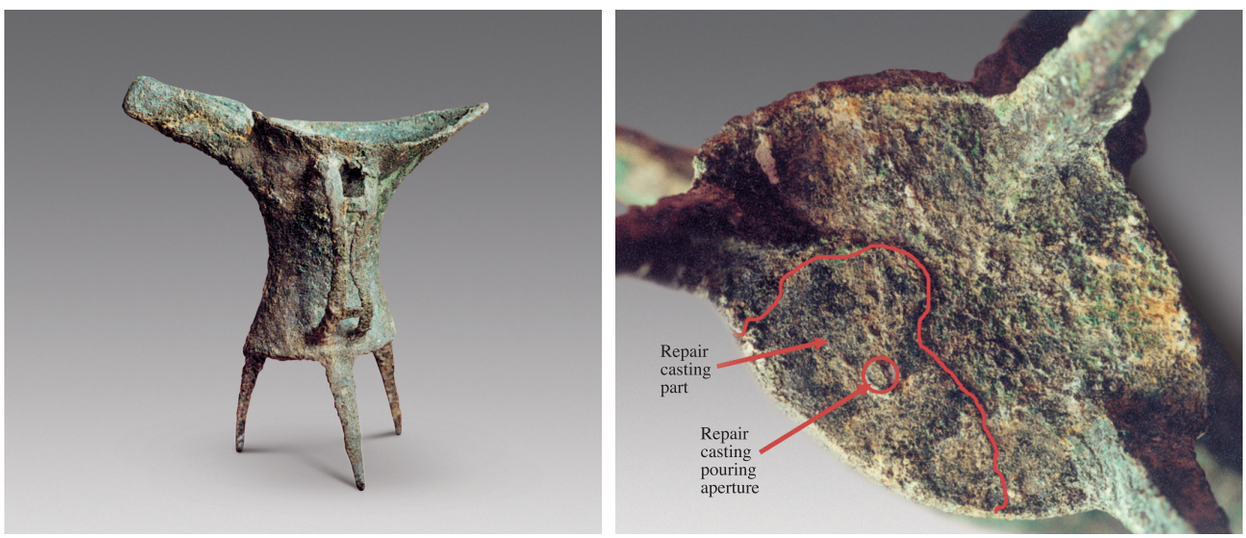

Figure 4 Bronze *jue*-cup (80YLIIIM2:1) unearthed in Erlitou Site.

Figure 5 Bronze bell unearthed in Erlitou Site.

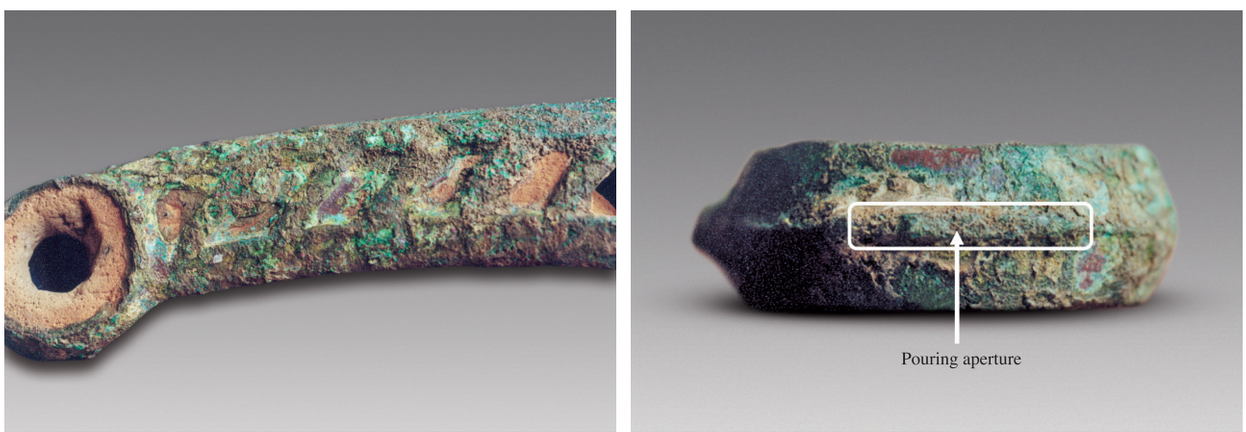

Figure 6 Bronze knife (80YLIIIM2:3) unearthed in Erlitou Site.

falling between 1–3mm. The uppermost thicknesses of the various vessel walls differed by no more than 1.5mm. The belly walls of one *jue*-cup in particular provided a total of 19 measurement data (Table 1), all of which fell between 1–1.2mm. This shows that the clay molds used at Erlitou underwent very little deformation during the production process, as well as that the positioning of the inner and outer molds was quite exact. No traces of the placement of bronze spacers or clay chaplets has yet been discovered on the bodies of vessels, indicating that regulation of the thickness of vessel walls relied on the positioning of the space between the outer and inner molds; on strict control of deformation of the molds; and on stringent measures for the assembly of the molds.

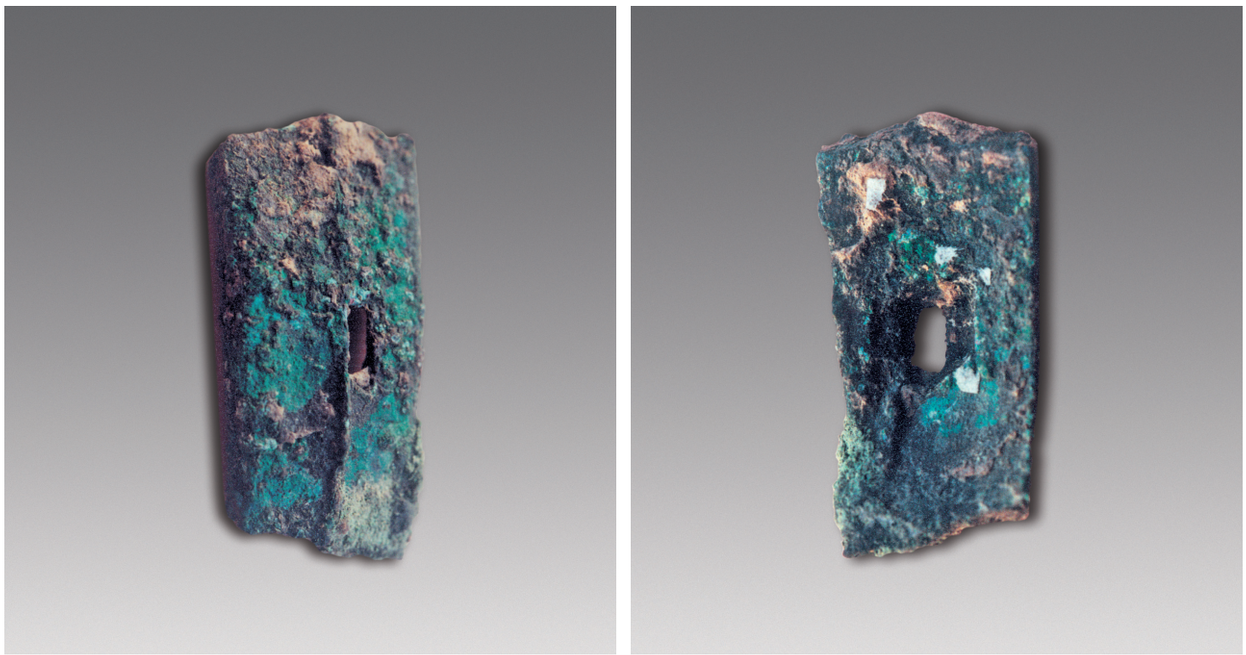

Figure 7 Bronze utensil fragments unearthed in Erlitou Site.

Table 1 Rim and base thicknesses of the spout of a bronze *jue*-cup from the Erlitou Site (unit: mm).

Measurement location								
Distance from the opening of the spout	15	30	45	60	75	90	105	120
Spout rim	1.0	1.0	1.0	1.0	1.2	1.0	1.2	1.0
Spout base	1.0	1.1	1.1	1.0	1.0	1.0	1.1	

The above investigation and analyses of bronze items from the Erlitou Site showed that a considerable level of technical achievement in bronze casting had already been attained by the Erlitou period. Bronze items were all cast in one piece. The divisions between mold pieces were relatively rational and their placement strictly and technically regulated; otherwise a *jue*-cup with walls of even thickness could not have been produced. Integrated supports were already used to hold casting cores in place. The casting designs of a few simple bronze types had already taken the forms in which they would be used throughout the Bronze Age. Repair casting techniques were already used to fix defects in bronze items; this was probably a particularly important factor in the development of multi-part and connecting casting techniques.

An investigation of clay molds unearthed at Erlitou Site

A relatively small number of clay molds already appear among the materials discovered from Erlitou Culture Phase I. By Erlitou Culture Phases III to IV, the number of clay molds increases demonstrably but is still limited.

1. The technique of making clay molds.

The clay molds are largely brick red, loess, or light gray in color. Their grain is typically somewhat loose, and most of them are relatively thick. Small pores of varying sizes can be seen on the broken surfaces, showing that the molds were tempered with plant matter. The firing temperature for those molds that had been fired was thus not high enough to reach sintering temperature. No suggestion has yet been found that the molds were produced from separate face and back layers. However, the facings of the model cavities and the parting planes are all quite smooth and fine without any holes, suggesting that they had undergone special processing using very fine clay (Figures 8 and 9).

Spirals, eye patterns, geometrical patterns, etc., all meant as mold patterns, were carved directly into the surfaces of the mold cavities of six mold fragments (Figure 10).

Two methods for positioning can be seen among the Erlitou mold artifacts: the carving of lines on the outer side of the molds and the use of positioning pins in the surface of the mold joint (Figure 11). These two

Figure 8 Clay mold (80YLIVT4) unearthed in Erlitou Site.

Figure 9 Clay mold (83YLIVH51:3) unearthed in Erlitou Site.

methods are still commonly used in the casting trade to this day; the former is simple and convenient, while the latter is more precise. At the time under consideration, the mortise-and-tenon positioning technique commonly seen among Shang and Zhou clay molds had yet to be discovered.

Around 10 clay pouring cups for casting have been unearthed, conical in shape, larger at the mouth and smaller at the base. These are of a relatively hard texture, having been fired at higher temperatures than the molds. During casting, these flared pouring cups would have served as funnels, facilitating the smooth introduction of molten bronze into the mold cavity; this would effectively have increased the speed of casting and the flow rate of the bronze. The pouring cups also increased the height of the casting form, thereby also increasing the total pressure exerted by the bronze when filling the mold, which would have been helpful for the casting of thin walls (Figure 12).

2. Testing of the clay molds.

Three clay mold fragments unearthed at Erlitou Site underwent chemical composition analysis, X-ray diffraction analysis, thermodilatometry, and phytolith testing. All of the molds were of a relatively loose texture, easily broken, with few large granules.

A compositional analysis based on X-ray fluorescence was conducted using a Quan-X model X-ray spectrometer. The molds were found to consist mainly of silicon dioxide and aluminum oxide, ferric oxide, calcium oxide, etc. The results of the analysis appear in Table 2.

X-ray diffraction analysis was conducted using a D/Max 2550V diffractometer under testing conditions of 40KV and 100mA. Analysis of the diffraction spectrum showed that the main mineral constituent of the molds was quartz, followed by mica and feldspar, all of which are primary ingredients in clay.

Thermal expansion curve testing was conducted using a model DIL 402 C dilatometer from the German brand Netzsch. The results showed the softening points of the molds to be at 1053° C, 1066° C, and 1051° C, high enough to endure the temperature of molten bronze during

Figure 10 Clay molds with designs on the cavity surface, all unearthed in Erlitou Site.

Figure 11 Clay molds with positioning pin or marks unearthed in Erlitou Site.

Figure 12 The clay pouring cup (83YLIVH20:11) unearthed in Erlitou Site.

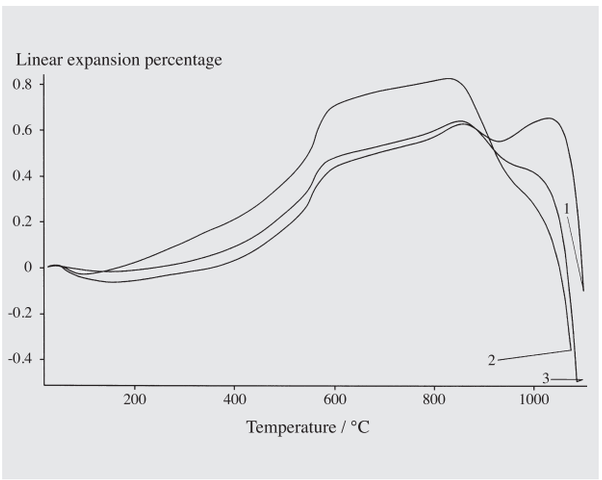

Figure 13 The thermal expansion curve of the clay mold fragments unearthed from Erlitou Site.

Table 2 Chemical composition of the three mold fragments from Erlitou (results of X-ray fluorescence analysis).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	MnO	K_2O	Na_2O	P_2O_5	Total
No.1	61.65	11.8	4.64	0.71	4.01	2.21	0.13	2.55	0.62	1.15	89.47
No.2	61.69	11.51	4.24	0.67	3.9	1.93	0.11	2.22	1.02	0.85	88.14
No.3	62.41	12.64	4.52	0.68	4.39	2.61	0.09	2.43	1.28	0.35	91.4

the casting process (Figure 13).

Phytolith analysis was conducted on the three mold fragments, with the following preliminary determinations: Reeds and other members of family Poaceae (grasses) had infiltrated the mold fragments. Other varieties of plants did not appear. As introduced in the excavation report (Institute of Archaeology 1999), "The Erlitou Site borders on the Luo River to the north. A trunk canal running east to west lies on the south side of the site; it is said that this was the old course of the Luo River… The Erlitou Site is fortuitously located atop a strand lying between the Luo and Yi [Rivers]... The soil here is fertile, the terrain level, the northern side densely forested, and the south side covered in reeds and grasses; the natural surroundings are quite harmonious." It cannot be determined whether the reeds and grasses contained in the mold fragments were intentionally tempered, or they were already mixed in the clay taken from the riverbank or the old river course to make the molds. However, these plant materials allowed the Erlitou clay molds to perform well for bronze casting, fulfilling the stringent requirements for casting bronze items with thin walls.

An examination of the foundry ladles from Erlitou Site

A fragment belonging to a ladle for the pouring of bronze during casting or perhaps to a crucible for the smelting of bronze (83YLIVH65:4) was unearthed at the Erlitou Site. It is oval in shape, with remnant bronze on its bottom portion; based on the remaining portion, it was probably 25cm in length. The texture of the clay ladle is relatively hard; the rear surface is reinforced by sticking a layer of straw-tempered clay, including numerous coarse plant fibers, and had undergone a firing process. The mouth of the ladle is relatively large.

The Erlitou Site also produced a foundry ladle with a spout. Molten bronze had adhered to its surface. It was used to accept smelted bronze from a crucible and to pour it into the mold cavity. With a foundry ladle, molten bronze could be introduced quickly into the pouring cup, facilitating the filling of the thin wall space in the mold. This is the earliest example discovered to date of a tool actually used in the casting process (Figure 14).

Conclusions

After an analysis of the bronze items, clay molds, and foundry ladles discovered at the Erlitou Site, the following preliminary conclusions may be reached:

1. The clay molds were fired at high temperatures, but did not reach sintering temperature.

2. The production of clay molds adopted some techniques from pottery production.

3. The techniques employed in the positioning of molds were quite rational. Integrated supports were already

used to facilitate the positioning of clay casting cores.

4. Pouring cups and foundry ladles demonstrated the early bronze casting technique.

In summary, the bronze items, clay molds and foundry ladles discovered at Erlitou Site confirm that bronze items with thin and even walls could be produced during the Erlitou period. These achievements show that the technical level of piece-mold bronze casting was already quite high by the early part of the Chinese Bronze Age, establishing a firm foundation for the developmental heights reached later in the period.

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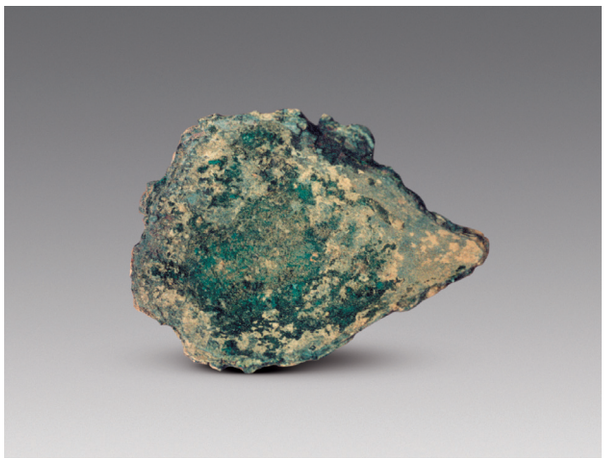

Figure 14 The clay foundry ladle with spout unearthed from the bronze foundry ruins at Erlitou Site.

Postscript

The original report published in *Kaogu xuebao* 考古学报 (*Acta Archaeologica Sinica*) 2011. 4: 561–75 with three illustrations, six tables and eight pages of plates was authored by Lian Haiping 廉海萍 , Tan Derui 谭德睿 and Zheng Guang 郑光 . The abridged version is prepared by Lian Haiping and translated into English by Paul Nicholas Vogt 侯昱文 .