LATE SHANG (1200 BCE – 1046 BCE) BRONZE CASTING TECHNOLOGY AND TECHNOLOGICAL BEHAVIOUR

by

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Abstract

This project examines the bronze casting technology of the late Shang Dynasty (1200-1046 BCE). Despite extensive scholarship on the bronzes themselves, the details of the casting process have remained unclear. Considering the relevance of the bronzes in terms of ritual and burial practices, class hierarchy, and royal affiliation, understanding the production behind the bronzes can reveal a great deal about the lives of everyday Shang craftspeople and Shang society as a whole.

This project examines bronze foundry remains from Yinxu, the ruins of the last capital of the Shang Dynasty, in an attempt to uncover more information about the late Shang bronze casting process. Emphasizing the behavioural nature of technology, and the information embedded within technological action, this project undertakes replication experiments to explore how the physical properties of the materials directly influenced the behavioural nature of the bronze casting process.

Scanning electron microscopy (SEM) suggests that the loess used to create bronze molds was processed differently than in other ceramics, with a notably reduced amount of clay. This information is integrated with an experimental program, which concludes that the removal of clay fundamentally facilitates the bronze casting process by minimizing shrinkage, providing structural stability and enabling long-term decoration. This has implications on the labour of the bronze-casting industry, emphasizing an initial process (the removal of clay) in order to facilitate mold construction, decoration and casting at later stages.

Examining the ways in which technologies are developed and used, and for what purposes, is a way in which archaeologists can examine past behaviour on both a personal and societal scale. The integration of petrographic analyses with an experimental program highlights how specific behaviours in the late Shang, such as materials processing and labour organization, are reflected in the technological remains of bronze casting. This project concludes that further examination into late Shang bronze casting technology is necessary in order to understand such a politically, socially and

spiritually significant industry of the time, offering insight into the daily perspectives of the Shang people due to the inherently behavioural nature of technology.

Preface

This dissertation is the original, unpublished, intellectual product of the author, Jasmine Sacharuk. The scanning electron microscope (SEM) data analysis in Chapter 4 was conducted alongside her supervisor, Dr. Zhichun Jing. The experimental research in Chapter 5 is of the author's own design and implementation. All tables and figures are original.

Table of Contents

List of Tables

List of Figures

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To my mother

for her unwavering support

(even after my teenage years)

Chapter 1: Introduction

The complexity and beauty of Shang bronzes is well known, but the technology behind their creation remains something of a mystery. While there is currently a general understanding of the method used to cast these bronzes (the "piece-mold method"), details of casting processes have not yet been illuminated (Bagley 2009: 39). Although the study of craft production has yet to be widely recognized in Shang archaeology, with a greater focus instead on the "historicity and cultural history of the site", there have been attempts to parse some of the finer details of this process (Li 2007: 194). Through bronze vessel analyses (Bagley 2009), replication experiments (cf. Fugen et al. 1982; Derui 1999), and microstructural analysis of casting remains (Freestone et al. 1989; Stoltman et al. 2009), scholars have provided insight into decorative carving methods, possible mold-making and casting procedures, and the material components of bronze molds. This thesis aims to expand upon this scholarship and explore how, in the production of bronze molds, the physical properties and manipulation of available materials influenced bronze casting and decorative processes.

This project looks specifically at bronze casting technology from the late Shang Dynasty (1200 BCE–1046 BCE). The last Shang capital of Yinxu (located in present-day Anyang, Henan, China) has revealed a massive array of bronze ritual vessels and foundry remains, as well as royal tombs, oracle bone inscriptions, and palace foundations that offer further contextual understanding for the bronze industry. This industry has shown itself to be a key element and sociopolitical tool in a deeply spiritual and hierarchized society, and understanding the details of bronze casting processes can offer insight into some of the dynamics of late Shang society as a whole.

Studying the details of the bronze-casting process is not simply an attempt to understanding the technology in and of itself; recognizing technology as a behavioural process, and studying it as such, can reveal dynamic relationships about the world in which it was situated. Dobres notes that “the ‘whole’ of technology rests with the *simultaneously* symbolic, social, and material experience of being-in-the-world” and that “disengaging these dynamics from each other, even for heuristic convenience, does that whole a terrible disservice” (Dobres 2000: 98). This thesis will explore the relevance of technology, not simply as a material solution to a problem, but as a way in which agents engage with and experience their world. Parsing out the details of technology can reveal a multitude of connections and thought processes that can help us, at least in part, connect to the world of the Shang craftsperson. Because of the general consistency of the mold-making materials, an added benefit of studying mold technology and the casting process is that it helps us understand Shang bronzes on a broad scale rather than focusing on particular bronze types.

In order to incorporate the experiential quality of technological behaviour with the material realities that influence that behaviour, I use replication experiments to engage with the bronze casting process and to experience the different choices with which artisans may have been presented. The experiments are informed by microstructural analyses of the bronze molds in order to provide a foundation for understanding the material choices and materials processing involved in mold-making. The experiments provide an opportunity for repeatable, testable observations that incorporate first-hand experience, and will illuminate some of the issues faced by the Shang artisan that may not be obvious without direct involvement.

The project aims to develop a social understanding of the ancient Shang bronzes through the technological processes involved in creating them. Chapter 2 begins by discussing the social and physical contexts of production in which the bronzes were created and Chapter 3 examines the behavioural aspects of technology that can serve as an indicator of social dynamics. Chapter 4 explores the physical properties of late Shang bronze casting remains that will inform the replication experiments of Chapter 5, which examines why the materials were processed and used in particular ways and how these materials influenced the bronze casting process. Chapter 6 concludes with some final thoughts, as well as some suggestions for future work. Understanding the constraints surrounding technological action, and the purposeful actions behind it, can help expand our understanding of the bronze casting industry and the wider social relationships surrounding it.

Chapter 2: Late Shang Bronzes and Casting Technology

Bronzes of the late Shang have been long admired, with interest stretching even before the Northern Song period (960-1126 CE), while non-Chinese art historians began to take an interest in these artifacts in the 1940s and 1950s using collections outside of China (Thorp 2006: 191). Their size, unique vessel types, and fine and complex lines throughout the decorative motifs continue to intrigue archaeologists, art historians and the general public. However, despite what we currently know about bronze development in China and the rich collections of bronzes that have been unearthed from Shang sites, archaeologists continue to be puzzled in terms of their specific methods of creation.

Late Shang bronzes did not arise spontaneously. In Gansu province, the Qijia culture has evidence of the earliest known metal industry ca. 2000 BCE. This is followed by the Huoshaogou site in the same province, dating to the first half of the second millennium (Bagley 1999: 140). Early bronzes in grave assemblages are present at Erlitou, which is both a site (located on the south bank of the Luo River) and a type-site of Erlitou culture dating to approximately 2000-1500 BCE often associated with the historical Xia dynasty. The bronzes from Erlitou culture sites indicate a shift toward casting, rather than the hammering technique predominating at the Gansu sites, a natural abundance of supplies and an increase in labour organization for mining and raw material procurement. However, bronzes are not as abundant in Erlitou as they are in Erligang culture sites, which date to around the 13-15th centuries BCE. Erligang culture, and its type-site Zhengzhou, is often considered the earliest part of the Shang dynasty and it is during this time that we can see an increase in bronze production and additional features that indicate technological development (Thorp 2006: 194).

This project focuses in particular on bronzes and bronze technology from Yinxu, the last capital of the Shang dynasty. The relevance of late Shang bronzes is connected to the spiritual and hierarchical nature of the society. Oracle bone inscriptions, palace foundations and royal tombs all indicate an expansive society with dynamic inner workings involving sociopolitical hierarchy, extensive and varied mortuary treatments and elaborate rituals and religious beliefs. Entangled among and between all of these elements is the complexity of craft production for a variety of artifact types. Bronzes and other objects, including pottery, bone carvings, jade carvings, permeated daily life, ritual ceremonies and burial practices.

Anyang, the modern city in which Yinxu was discovered, is about 550 kilometers south of Beijing, located in Henan Province. The terrain is flat loess, located between the Taihang Mountains in the west and the Yellow River to the east. The Huan River, a tributary of the Yellow River, runs through Anyang (Figure 1).

One feature of Yinxu is an ancient ceremonial center, known as Xiaotun, containing a kingly-lineage settlement made of rammed earth (*hangtu*). The Xiaotun area at the bend of the Huan River, also known as Xiaotun Locus North, features a number of building foundations interpreted as the remains of palaces and temples, and is considered a “sacro-administrative center” (Keightley 1999: 252). Due to the size of the building remains, sacrificial burials and deposits of inscribed oracle bones, it is reasonable to assume that this area was a main area of royal and religious activity starting with the king Wu Ding (Bagley 1999: 184).

Anyang features a number of massive tombs with immense grave good deposits, as well as other types of mortuary treatments including sacrificial burials. Over 10,000 burials have been found in Yinxu, as well as residential settlements, bronze foundries, and numerous workshops dedicated to pottery, jade and bone (Jing et al. 2013:351). The tomb of Fu Hao, Wu Ding’s consort, is particularly important because it is the biggest unlooted tomb found from the Shang period. Also known as Tomb 5 or M5, and located northwest of Xiaotun Village, it contained 468 bronzes (altogether weighing over 1500 kilograms), 755 jades and 6800 cowrie shells (Keightley 1999: 264). Fu Hao’s tomb has been useful in identifying the mortuary treatments of high status individuals, and has also allowed archaeologists to analyze the various jades, bronzes, pottery and other objects within the tomb to see a plethora of styles and techniques present at that time.

The size of Fu Hao's tomb was still relatively small in comparison to those found at Xibeigang, a royal cemetery with sacrificial burials and gigantic shaft tombs (all of which were looted prior to excavation). The labour required for the construction of these tombs, along with the extensive grave goods, is indicative of the extreme wealth and status of the Shang kings and their royal associates and the political organization involved in maintaining this hierarchy. Medium-sized pits and shallow pits are also present, while burials in refuse pits clearly indicate the treatment of low status individuals (Keightley 1999:267). Over 1200 sacrificial burial pits, mostly with human victims, have also been found among the large Xibeigang royal tombs (Bagley 1999:192). The variety of burial types "reflect the secular world and practices", and reveals to us the importance of status in both life and death during the Shang dynasty (Keightley 1999:262). The sacrificial burials are a further indication of the dominion of ancestors over the living, and the prominence of religion in Shang daily life.

Considering the predominance of bronzes in mortuary contexts, it is reasonable to infer that the bronzes played a major role in funerary rituals. Nelson (2003: 67) notes that cultures preceding the Shang, like the Dawenkou, also seemed to have feasting in mortuary ritual. The Dawenkou grave goods suggest status differences, although food and drink do seem to have played a role in mortuary ritual for all kin groups (Nelson 2003: 67). Judging by the elaborated tall stemmed ceramic cups found in burials, wine in particular seems to have played a key role, possibly to facilitate interaction with the dead (Nelson 2003: 68). For the late Shang, food and wine containers shifted to bronze, a costly switch indicating the significance of both the interred and the associated ritual activities. Nelson remarks that bronze containers for meat were present in Fu Hao's tomb. The tomb also contained a bronze cooking stove and bronze cooking pots, which were likely used for cooking grains based on contemporary analogy (Nelson 2003: 85). Soot was found on the stove, indicating it was used before burial (Nelson 2003: 85). Rawson (1996: 87) speculates that "the large number of different but set shapes suggests a formal meal, with prescribed foods and wines offered in a prescribed sequence". Bronzes thus played a significant role in a society that placed great emphasis on ritual and spirituality.

The significance of the bronzes is also reflected in the growing intricacies of their decoration and complexity of their casting process. Art historian Max Loehr (1953) arranged a sequence of five styles of development after analyzing unprovenanced bronzes. At this time no pre-Anyang sites had been excavated, so Loehr connected these styles to Anyang. After Erlitou and Erligang sites had been discovered, however, the earliest styles in his sequence were demonstrated to align with these cultures. Style I features singular bands of decoration, the motif most commonly a two-eyed animal pattern called a *taotie*. The subsequent styles begin to vary their line sizes and reliefs, and begin to add more layers to the patterning through an increasing use of differing relief depths. Style IV and V utilize a *leiwen* spiral pattern that surrounds images, the patterns become more harmonious and uniform and they tend to cover the whole vessel. Style IV and V are attributed to Yinxu periods I and II, the early phases of Anyang. While his sequence has been refined and reworked over the years by numerous scholars, Loehr's framework has proven to be an important and helpful guideline in dating bronzes and also in recognizing technological developments and choices. As Robert Bagley (1999: 147) notes, these styles should not be viewed as isolated trends but "as steps in the elaboration of a growing repertoire"**.**

Max Loehr's stylistic sequence focuses on the decorative analysis of these bronzes, but fully understanding the technology of late Shang bronzes also requires a direct analysis of the ceramic casting remains used in bronze production. Fortunately, major bronze foundries such as Xiaotun, Dasikongcun, Miaopu and Xiaomintun have been discovered (Li 2003). The foundry remains studied in this project are entirely from Xiaomintun, which was excavated in the springs of 2000 and 2001 by the Anyang archaeology team, Institute of Archaeology, Chinese Academy of Social Sciences (CASS). Due to the poor preservation of Xiaomintun, dating the site is difficult, but the types and styles of the bronze molds suggest an occupation spanning from as early as Yinxu II to the beginning of the Western Zhou period (1046BCE - 771BCE). However, the vast majority of the types and styles of bronze vessels represent late Shang phases (Yue 2007: 38). Over 30,000 mold fragments, primarily for casting ritual vessels, as well as ~200 core and model fragments, were discovered in an excavation area of about 5000 km^2 (Yue 2007: 31). Over 1000 straw-tempered and ~100 sand-tempered crucible fragments were found as well (Yue 2007: 33) The site also revealed 160 Shang period burials and 12 foundations but the layout of the foundry site remains unclear (Li 2003: 210). Given the foundry remains (mold fragments, crucible fragments, grinding stones, charcoal, furnace pieces, bone awls for carving and surfaces for bronze finishing), it appears as though Xiaomintun was used for mold-making, casting and finishing (Li 2003: 222).

In 1935, Orvar Karlbeck studied bronze casting molds and concluded that the bronzes were cast using the "piece mold" technique, as opposed to the lost-wax method employed in the major bronze foundries of Ancient Greece and Rome (Karlbeck 1935). However, this view was not firmly established until the 1960s (Bagley 1990: 7). In the piece-mold technique, clay is used to cover a model (also made from clay or possibly wood), and is then sectioned off and reassembled with negative space remaining on the inside. To ensure bronzes were hollow on the inside, additional clay pieces called "cores" were also added to guarantee that molten bronze would not fill the space. A typical wine vessel, for instance, would require at least three sections and a core, along with additional pieces for handles and legs. As an increasing number of vessel types were incorporated from ceramic correlates, "different and more elaborate assemblages of molds were devised"

(Freestone et al. 1989: 254). Although piece mold casting is complex and difficult, it allows the interior of the casting structure to be available for additional decoration. It also removes the need for soldering or riveting, allowing any joins to be cast on directly.

However, it is still puzzling how Shang craftspeople were able to form molds large and stable enough to cast bronzes like the Simuwu Ding (over a meter high and wide, weighing 875 kilograms), and were able to cast such bronzes without soldering or riveting additional pieces. Moreover, casting the bronze directly must have resulted in "enormous quantities of metal", particularly considering the sheer number of bronzes that have been uncovered, suggesting that mining operations were massive and complex (Freestone et al. 1989: 257). Considering the size of some bronzes, the large quantities that were buried, and the number of tombs that likely included these bronzes (prior to looting), "the use of casting and elaborate burials therefore demanded a massive, highly organized industry" built upon sophisticated technological knowledge (Freestone et al. 1989: 257).

Karlbeck's conclusion was a significant stepping-stone for understanding the extent of Shang bronze production, underscoring how the style, decoration and function of bronze artifacts are fundamentally shaped by this casting method. The bronzes functioned as an important symbol of spiritual and sociopolitical power, but the time and labour required to facilitate this complex bronze industry underscores the immense role that they played in daily life as well. The recognition of piece-mold process in late Shang bronze casting highlights how technology can greatly influence how we come to understand a particular society and the ways in which particular industries are organized. This project continues this line of thinking through the continued examination of late Shang bronze casting technology. The following section explores current theoretical understandings of technology in order to underscore technological behaviour and its reflection of the surrounding world in which it is situated.

Chapter 3: Technology, Behaviour and Style

The term "technology" has varied and sometimes conflicting applications, but the behavioural nature of technology has been increasingly emphasized in archaeological research and other disciplines (Dobres 2000; Franklin 2004; Heidegger 1977; Lechtman 1977). Scholars now stress "the nature of technology as *practice*, as ways of doing or making something, of organizing work and people into systems involving new words and new mindsets as well as new tools" (Miller 2007: 4). Rather than focusing simply on the end products of technology, the actions and minds *behind* these products are also being highlighted. Lechtman (1977: 276) suggests that technologies are communicative "performances" filled with symbolic action and Franklin (2004**:** 5) argues that technology "is a multifaceted entity" that "includes activities as well as a body of knowledge, structures as well as the act of structuring". While scholars focus on different aspects of technological action, Miller (2007: 4) notes "the resulting examination of the entire process of technology, including the social context, is one of the most exciting trends in the study of technology".

This project identifies in particular with the conceptualization of technology highlighted by Dobres (2000), who outlines a specific practice framework for archaeologists connecting technology and human action. Dobres (2000: 96) views technology in a holistic manner, avoiding an artificial separation between "heuristic spheres" like social organization, artistic creation and belief systems. Instead, technology, in practice, "is a dynamic web weaving an unlimited number of factors, or threads, into a seamless whole" (Dobres 2000: 96). One must not conflate the material remains of technology and the social processes they are related to, recognizing instead that technology is "centrally about the meaningful social relationships people forge, reaffirm, and contest while going about such activities" (Dobres 2000: 61).

Dobres draws upon the work of philosopher Martin Heidegger (1977), whose reflections on the relationship between humanity and technology continues to be incredibly influential across disciplines. She specifically pinpoints the Heideggerian notion of Dasein, or being-in-the-world, which emphasizes the "continually unfolding process of human existence *in* the everyday material world" and highlights how people "give meaning to and transform their world through the immediacy of the direct and socially constituted experiences they have when working materials" (Dobres 2000: 97). A potter, for instance, specifically engages with the physical and social aspects of his or her surrounding environment, coming to understanding the different qualities of each through the use and manipulation of materials. The potter learns how to navigate through the material and social world by inheriting stocks of knowledge, by learning where and how to acquire materials, and by interacting in the social and political systems that surround and control production processes. These experiences are of course not limited to craftspeople alone; one engages with overlapping and interacting technological systems constantly throughout ones' lifetime. However, understanding the technological action behind the creation of a particular artifact is a direct way in which archaeologists can connect to social dynamics of ancient society and ancient industries that are otherwise obscured.

Technologies are not simply reactions to the surrounding world, but ways in which people come to experience and shape it. Technology encompasses both the social and the material, and is thus an essential part of understanding the social dynamics of the ancient past. Cyril Stanley Smith, a metallurgist and historian of science whose scholarship has been particularly influential in understanding ancient bronze production methods, routinely highlights the connection between art, behaviour and technology. Smith (1977: 145) states that works of art are usually enjoyed "for their outer form and symbolism alone, and appreciated as a statement of the artist's ideas on some aspect of the world, an expression of the forms and feelings that he selectively absorbed from the culture of which he was apart" but must also be appreciated as "an object and as such a product of technology".

He further argues that historians of science, art historians and archaeologists all "commonly overlook the fact that the thoughtful intimate awareness of the properties of matter first occurred in the minds of people seeking effects to be used decoratively" (Smith 1977: 145). Material properties form a significant element in understanding a social-relational context, because physical aspects constrain the choices of craftspeople, influence their production processes and shape decorative elements. By studying material properties, technology and art in conjunction with each other, we can flesh out certain elements of craft production and behaviours that are obscured when studying the decorative aspects of the artifact alone.

The study of Shang bronze casting technology has been less extensive in comparison to the study of Shang bronze decoration, leaving a void in fully understanding the relationships surrounding these remains. However, Orvar Karlbeck's (1935) study of Shang bronze molds, as mentioned, led to a broad understanding of the casting process while Robert Bagley's (1990; 2009) analyses of Shang bronzes and bronze molds have also explored Shang bronze production. Bagley's research considers how the construction of molds may or may not have influenced decorative elements such as flanges and vessel shape. He also specifically takes molds into consideration in order to understand the fine decoration of Shang bronzes, using both molds and bronzes to argue that the decoration was likely transferred from a model to a mold, with finer carvings then added directly onto the mold (Bagley 2009).

Bagley's analyses of Shang bronzes and bronze molds have contributed greatly in emphasizing the relationship between casting technology and bronze decoration, and highlights the importance of studying the actions preceding the final product. This project also emphasizes the actions surrounding an artifact's creation by focusing on the *chaîne opératoire* of late Shang bronze technology. *Chaîne opératoire* has been employed as the series of operations (starting, for instance, with the collection of raw materials) resulting in the final product and, ultimately, to its discard

(Lemmonier 2002; Van Der Leeuw 1993). The *chaîne opératoire* takes into consideration the multiplicity of elements and processes that are embedded in a single artifact, underscoring a holistic perspective.

This project undertakes replication experiments, as experimental archaeology is a way in which the behavioural aspects of technology and the *chaîne opératoire* of an artifact can be studied together. Experimental archaeology is an iterative process built from cumulative experimentation and involves "the fabrication of materials, behaviours, or both in order to observe one or more processes involved in the production, use, discard, deterioration, or recovery of material culture" (Skibo 1992:18). These experimental programs pay great attention to research design and procedure, allowing "modern analogies generated by experiments to clarify past behaviours and practices" (Ferguson and Marsh 2010: 2). Moreover, experimental archaeology provides an opportunity for archaeologists to test data through repeatable experiments, and explore alternate possibilities through multiple tests of the same experiment with different variables. Since it is possible for different tools, processes and interactions to theoretically result in the same final product, replicative experiments can provide insight into why certain choices were made in forming a particular technological style through firsthand experience and variable testing. A number of replication projects have been conducted regarding Shang bronze casting technology, and they have been crucial in understanding possible methods and techniques (see Li 2003: 58-76 for a comprehensive overview). However, these projects did not have the benefit of analyzing the microstructure of the Anyang molds as a stepping-stone for understanding how the physical properties of the molds differ from other Shang ceramics.

In contrast, this project employs microstructural analysis as an initial step in refining the variables of the experimental process. As noted earlier by Smith (1977), material properties are a key component and key constraint influencing and highlighting the choices made by artisans. By determining the specific raw materials and processing techniques involved in mold-making, one can experience firsthand the difficulties and benefits in working with these materials, why particular choices were made, and how these choices influenced and/or were influenced by desired decorative or functional elements. Embracing physical properties as a key component in the behavioural aspect of technology can reveal a multitude of other behavioural factors and choices involved in the craft production process, and subsequently reveal information about socio-cultural processes surrounding it as well.

Understanding technology means that we conceptualize it as communicative and behavioural. Interrelated, complex relationships of surrounding factors result in particular ways of action, such as technological action, and an expression of these factors are ultimately bound up in the actions and their physical remains. Therefore, if one directly studies the sequence of technological processes leading up to the production of an artifact in conjunction with its functional and stylistic aspects, one can expand upon the interactions and constraints involved between and among these spheres.

Chapter 4: Soil Properties and Microstructural Analysis

4.1 Relevance of Microstructural Analysis & Scanning Electron Microscopy (SEM)

As noted by Cyril Stanley Smith (1977: 145), examining the physical properties of ancient technology can reveal a great deal about the aims of its creator(s), since "man must select material having a 'nature' that will conform to the larger shapes that he wishes to impose upon it". Since the goals of a Shang artisan are shaped by and reflected by the physical properties of his or her working materials, directly examining the physical properties highlights the purposeful selection of materials and the goals associated with these choices. Fully investigating the microstructure of the molds therefore provides a material foundation upon which my replication experiments will be built.

The compositional relevance of Shang molds and pottery is recognized in studies by I.C. Freestone (et al. 1989) and Jim Stoltman (et al. 2009), both of which will be elaborated upon in the following section. Stoltman's study employed a polarized microscope to investigate the microstructure of Shang ceramics, while Freestone examined bronze molds through the use of scanning electron microscopy (SEM) in backscattering mode (BSE) and energy-dispersive X-ray spectroscopy (EDX).

Alongside Freestone, this project has used BSE and EDX to analyze additional samples, primarily from the casting foundry at Xiaomintun, for further illustration of the general compositions of Shang pottery and mold remains. In scanning electron microscopy, atoms of a particular sample are struck with a concentrated bundle of electrons (an electron beam), and the atoms are subsequently reflected or backscattered out of the material to produce a grayscale image that includes compositional and topographic information (Krinsley et al. 1998: viii). If the sample is made into a thin section prior to analysis, an enlarged image, along with the "identification of mineral constituents, their relative abundances [and] associations and states of alteration" is possible (Rapp

2009: 25). BSE is particularly effective for mineral identification because of its excellent resolution and contrast, and the high magnification that is possible. Using BSE also allows for a quantitative determination of the relative abundance of minerals, as well as quantification of grain size and form (Krinsley et al. 1998: 26). EDX, meanwhile, measures the unique atomic structure of each element, presenting them as a unique set of peaks on an X-ray spectrum. EDX however cannot detect elements with molecular weights below that of carbon and cannot identify particular bond structures, and is thus only used for the detection of inorganic compounds. The use of BSE in conjunction with EDX "provides a powerful tool for mineral identification, porosity determination, and study of fine-scale grain-to-grain and intra-grain relationships", and is useful for differentiating between mineral phases like quartz, feldspars and clays (Krinsley 1998: 52). The BSE/EDX suite has been an excellent source of information for understanding the microstructural composition of Yinxu ceramics and bronze molds. The BSE/EDX figures included are drawn from this project's analyses alone.

4.2 Microstructural Analysis of Shang Pottery

Understanding the material selection of the Shang molds first requires an understanding of Shang ceramic technology in general. Comparing the materials selected for pottery vessels with those for molds will highlight the particular differences between these ceramic types, and will underscore the unique recipes used for bronze molds.

Recent petrographic analyses by Stoltman (et al. 2009) of different ceramic remains from Yinxu show that the ancient craftspeople specifically utilized different clay recipes for different goals. Stoltman demonstrates that a large portion of Shang pottery was made from temperless local loessic sediments, composed of quartz, mica and feldspar, in addition to clay minerals (Figure 2). Although it is less dense than other soils, loess has excellent dimensional stability and can be used to form stable structures, which lends itself well to both pottery and mold-making. Loess is also successful for ceramics in large part due to its low clay content and low firing temperature which allowed for low shrinkage after drying or firing (Kerr & Wood 2004: 119).

Some vessels, such as a typical *gui* container analyzed in Figure 3, tended to have high or intermediate levels of silt and small amounts of sand, along with a rich clay matrix (Figure 3)[1]. Vessels such as these were used for "transport, serving, and storage" and notably not for cooking (Stoltman et al. 2009: 190). The loess used for these vessels could have been acquired easily by non-specialists to make pottery for everyday use and did not require significant processing for its purposes (Stoltman et al. 2009: 198).

In contrast, Figure 4 shows the composition of a *li* cooking vessel, composed of local alluvium tempered with sand. The potters preferred to temper alluvial sediments, transported by the Huan River, which have less silt content than loess and are also denser (Stoltman et al. 2009: 195). Stoltman's study suggests a strong correlation between sand-tempered vessels and their function, with 15 out of 16 tempered samples being associated with cooking vessel types (Stoltman et al. 2009: 195). This association likely reflects the "potters' intent to enhance the performance properties of vessels designed for specific functions"; in this case, it is reasonable to suggest that the potters tempered the vessels to minimize thermal stress, allowing the vessels to be reheated regularly without cracking (Stoltman et al. 2009: 195).

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[1] According to the standards of the International Society of Soil Science (ISSS), clay particles measure <2µm while fine silt measures from 2µm-6µm, medium silt from 6µm-20µm, and coarse silt from 20µm to 60µm. Sand measures from 60µm-2mm (Blott and Pye 2012: 2076).

4.3 Mold Microstructure

The purposeful choices of the potters demonstrates an intimate knowledge of soil properties that were subsequently exploited to enhance functionality and achieve a particular goal; choices such as these are also reflected in processing of soil for the purpose of bronze mold-making.

Like Shang serving vessels, the molds have very similar mineralogies and micromorphologies as loess in terms of non-clay particles (e.g. quartz, feldspar, mica, calcite and amphibole), strongly suggesting that molds are manufactured from loess (Freestone et al. 1989: 260). In contrast with Shang pottery however, bronze molds contain little clay and no sand, suggesting that the artisans either sought out loess deposits with little clay or they processed the loess for clay removal (Figure 5). Freestone (et al. 1989: 270) argues that it is more likely that the artisans carefully selected certain loess deposits for low-clay content, stating that processing is "unlikely as several distinct procedures would have been required to remove both very fine (clay grade) as well as very coarse (sand grade) material from the silt". However, considering the quantity of loess required for the bronze casting industry, and the amount of clay present in average loess samples, I believe it is more likely that the loess was processed via sieving and levigation (immersing the soil in water, waiting for heavier particles to sink to the bottom and removing the top layer of lighter materials). In either case, the SEM samples firmly demonstrate that the artisans deliberately sought a low-clay content, likely because this reduces shrinkage and thus minimizes damage to mold fitting and decoration.

With very little clay, which is sticky and plastic, the silt-based molds would have also required a type of binding material. Although Freestone (et al. 1989: 269) argues that the loess chosen for the molds was low in lime contents in comparison to most loess samples, this project's EDX analyses reveal the presence of large calcium deposits, suggesting that limestone may have been slaked (transformed into calcium hydroxide using heat and water) and used as a binder (Figure

6). The source of the discrepancy behind Freestone's results and this project's analyses is presently unknown and warrants further study, as this issue is beyond the bounds of this thesis. However, the clear difference of CaO levels between a mold sample and a pottery sample (made of unprocessed loess) contradicts Freestone's findings and further strengthens the possibility that lime was added to the mold recipe (Figure 7). Another sample demonstrates a distinct boundary between the calcium and the loess suggesting that the calcium was specifically added, perhaps representing a poorly mixed sample (Figure 8). Calcium deposits can occur naturally, but not in such a saturated and bounded manner. This also would have been a feasible addition as limestone, slaked after collection, would have been readily accessible in the nearby Taihang Mountains.

The molds also contain a substantial number of large pores/voids compared to Shang pottery (Table 1). For this project, four mold BSE images and three pottery BSE images, all at x500 magnification, were analyzed using the open-source software ImageJ. The threshold of the images were adjusted in order to distinguish the minerals (represented as white) from the pores (represented as black), and the software calculated the percentage of black space in the image (Figure 9). The percentage of voids in the mold samples was between 17-25%, while the voids of the pottery samples were between 0.40-12% of the composition. The percentage of voids calculated from a loess sample was 6.31%. The consistently high porosity of the molds in comparison to both pottery and unprocessed loess suggests it was specifically implemented, most likely to encourage gas to escape evenly during bronze casting to prevent extreme thermal stress. The specific techniques for creating the voids are still unknown. EDX analyses of the voids were unable to detect any elements; considering the limitations of EDX in identifying organic compounds, this suggests that the voids were created using added organic material. Thus, it is possible that the voids are the result of an added organic material that is subsequently burned out during the baking of the molds.

These studies highlight the dynamic and integrated relationships between the physical nature of materials and the technological behaviour of the craftsperson. Purposeful choices are reflected in the microstructural differences between different types of ceramic remains from the late Shang and bronze production fundamentally relied upon and was shaped by the intimate knowledge of soil properties by ancient artisans. The following section employs this knowledge of bronze mold microstructure to explore how differences in technology are reflected in behaviour, and how this influenced the nature of the bronze casting industry.

Chapter 5: Replication Experiments

5.1 Introduction

This experimental program is predicated on the idea that technology is behavioural. Even when the details of technological action are known intellectually, the act of engagement in the process can highlight and reveal nuances that might be otherwise obscured. In this case, the process of mold-making using loessic materials from Anyang can provide substantial insight regarding Shang bronze casting practices, the bronze industry, and Shang society in general. It would be impossible however to solve every unanswered question regarding Shang bronze casting technology. Therefore, in order to narrow the scope of the program, the experiments set out to address the following: 1) From an artisanal perspective, why were particular materials and techniques employed by the Shang (e.g. which materials and processing techniques facilitate the mold-making process)? and 2) What elements about late Shang society, if any, are suggested from the conclusions drawn through this experimental program?

This work is situated within ongoing experimental research conducted at the Anyang Work Station, the permanent field facility of the Institute of Archaeology at the Chinese Academy of Social Sciences. Other details of the bronze casting process, such as kiln construction and crucible technology, are also being experimented upon at the station. While the experiments presented here were conducted during one field season, certain details (such as carving technique and dung content) build on experiments from previous seasons as well.

The replication experiments in this project are informed by the aforementioned SEM and EDX analyses. Thus far, SEM analyses clearly indicate that the molds have very little clay and have a large percentage of voids that are likely attributable to organic material. Freestone (et al. 1989: 260)'s EDX analyses confirm the use of loess for mold creation, while my own analyses suggest the possibility of lime (calcium carbonate) as a binder and organic material for the creation of voids. Thus, these experiments attempt mold-making with a variety of “recipes” using clay, silt, lime and/or cow dung[2] (organic material for the voids). Because the experiments focus on the material properties of the molds in particular, some other elements of the bronze casting process were not replicated exactly as Shang artisans would have done. In some cases this is because the exact processes are not yet known (e.g. specific procedures in making carving tools, melting metal without the aid of modern instruments) and in other instances it is for the sake of time (e.g. using running water rather than collecting water from the Huan River).

5.2 Experimental Procedure

The soils collected for these experiments were from Dasikongcun, an area with an immense number of burial tracts for the petty elite dated to the late Shang period. The soils were collected from a large pit, specifically from buried A- and C-horizon that would have been available during that time. The C-horizon soils were primarily used for model-making while the A-horizon levels were used for mold-making due to its higher silt content.

Both the A-horizon and C-horizon soils were first sieved to remove especially large particles and were then extensively levigated -- a process of separating coarse and fine materials by immersing and mixing a sample in water and letting the heavier material settle to the bottom -- to separate the sand, silt and clay. Approximately 15 L of A-horizon soil was levigated at a time. The soil was mixed with water by hand and would be left to settle in the water for 3 minutes (based on trial and error

[2] Cow dung was chosen for this experiment due to its consistency, which is pliable enough to be easily distributed throughout the mold recipe in the same manner as the voids. Cow dung was also easily accessible for the Shang, who domesticated cattle (Chang 1980: 143). However, it may be worthwhile to test other organic material (e.g. straw, seeds) in future experiments.

from past seasons). For this particular experiment, both the silt and clay were desired. Thus, the lighter material suspended in the water (clay) was poured into a separate container and was levigated again; this process continued until the water on top ran clear. Once 3-4 containers contained primarily clay, these containers were combined and levigated again. The same occurred with containers of silt. While the number of cycles varied for each sample, each original 15 L amount needed to be levigated at least 10-12 times, while the subsequent containers were levigated 2-3 more times. Thus, the process became more time consuming as it went on due to the increasing number of containers requiring levigation. On my own, I was able to levigate about 30 L of soil per day. Without running water, requiring instead the collection of water from the Huan River, this process would have been substantially longer.

After the clay and silt had been separated[3], the containers (of similar material – e.g. the containers containing silt) were poured over pits covered in tightly woven burlap and left to dry, leaving silt samples, clay samples and silt and clay mixtures. Seven bags (approximately 30 L in volume each) of A-horizon soil yielded 2 containers of silt, 1 container of clay and 3 containers of silt and clay mixture (all containers were 40 L in volume, but were only filled to approximately ½ to ¾ of their capacity). The resulting yield is therefore ~57-75% of the original material, with silt accounting for ~19%-28.5%. Both the initial sieving of large particles and issues with the levigation process (minor spills, silt/clay residues on containers, small amounts of material in discarded water) can account for the lost material.

Once the different components were collected, small blocks of the different recipes were made to measure shrinkage. The recipes were: silt + clay mixture, clay alone, silt + lime (5%), silt +

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[3] Technically the clay and silt will never be entirely separated and each collection will contain an element of the other. The clay could be referred to as "silty clay" and the silt could be considered "clayey silt" but for simplicity this project will refer each as simply "clay" and "silt".

lime (2%), silt + dung (2.5%) + lime (5%). These recipes were based on my own experimentation from both this season and a previous season. A preliminary test of silt + lime (10%) rendered the material totally stiff and unworkable, suggesting that a smaller amount would be more successful. The amount of dung (2.5%) was based on past experimentation; due to the size of the dung particles, larger amounts (5-10%) tended to complicate fine carving by obstructing the carving tool. (A block of only silt was initially made as a control, but because silt does not bind to itself it was impossible to keep the block intact).

The lime putty was purchased from an online retailer and had been aged (kept under water) for about two years. There is no consensus on how long to age slaked lime, with Ashurst (1990) arguing it should be kept under water a minimum of two months and traditional methods requiring multiple years of aging (Cazalla et al. 2000). While the specifics are not agreed upon, it has been observed that the long-term aging of lime "results in a significant improvement of $CA(OH)_2$ plasticity and water retention" that would be useful in binding the silt of the bronze molds while also remaining malleable (Cazalla et al. 2000: 1071). In our own experiments from the previous season, the lime that had not been aged and this was substantially less effective than in the experiment described here.

Cow dung was collected from local farms and processed through sieves to separate the solids and liquids. In some of my experimentation, I primarily used the liquid portion of the cow dung, and in other molds I primarily used the solid portion. The differences will be clarified below.

Each block was initially measured to be slightly longer than 10 cm in length, with a 10 cm line carved into it. The 10 cm line was also segmented into 1 cm intervals. Each block was left to dry for 48 hours and subsequently measured, then baked in an open-air kiln and measured as well. The blocks made of primarily silty material experienced very little shrinkage (<1 mm), while blocks containing clay shrank substantially in comparison (~4 mm) (see Table 2). This confirms that one of the benefits of using silt for mold-making is its resistance to shrinkage, as it would be able to retain decoration without substantial cracking or warping of the design.

After testing the shrinkage, I began making my model. The model was carved out of a C-horizon clay + silt mixture. Far fewer models have been found than molds, but it appears as though models were made out of a variety of materials (e.g. bone, wood, clay) (Thorp 2005: 143). Their materials are less specific for a number of reasons. First, models do not need to be sectioned off and refitted, so structural stability and a lack of shrinkage are less important. Moreover, judging from my own physical analyses of ancient models and molds from Anyang, it appears as though the larger decorations are carved directly onto models and transferred to the molds and finer carvings (like the *leiwen* cloud designs) were carved directly onto the molds. Thus, the models do not need particular material properties to retain fine decoration elements that molds do. Finally, transferring the larger designs from the model to the mold is much easier when they are made of different materials, as materials of a similar nature will bind together.

The model drew upon *taotie*, a symmetrical mask motif commonly found on Shang bronzes (Figure 10). The *taotie* design was chosen primarily due to its frequency on Shang bronzes in order to explore whether the chosen materials influenced the symmetry and geometry of their design. The model was also made fairly thick and wide, similar to a panel on a bronze vessel, to test whether these particular mold recipes would be able to cast something of this size successfully without breakage.

The model started off as a rectangular brick of clay, and was shaped to have an even incline on two sides to emphasize the symmetricality of the design (Figure 11). The brick was dried for 24 hours. Thick copper wire, straightened with a hammer and sharpened with an electric grinding wheel, was used for carving[4]. After the carving was completed, it was fired in an open-air kiln to harden it and ensure its durability.

Once the model was done, a number of molds were created using the same recipes as the shrinkage bricks, based on 500 mL volumes. An initial slab of each recipe was created slightly larger than the approximate length and width of the model. The mold recipe was left to dry on the model for approximately 5-10 minutes (until the surface was no longer moist) so that it wouldn't be too soft to lose its shape. This initial slab was then removed. For some slabs, additional decoration would be added (or attempted) while still fairly wet, while others were attempted after substantial drying (leather hard). Usually the main decorations from the model would need to be touched up, and a small sample of finer details would be added at this point as well.

Observed on Anyang bronze molds are also mortises and tenons – a small cut would be made on one side of the mold, and the other side would be pressed in to form a matching piece that fits inside (Figure 12) to secure the two pieces together. At this point, I made two small triangular cuts in the initial slab (mortises) on each side. I also took this opportunity to create a half-circle hole where I intended to pour in the bronze, as well as a path connecting the hole to the rest of the design. These small paths can also be seen on Anyang molds, which helps guide the molten metal through the whole design. Without these small tracts, the molten metal can end up piling in one spot rather than distributing evenly.

After these additions, I then covered the back of the model with another slab, removed it, and joined it with the initial piece. I would ensure that this piece would be fully pressed into the mortise of the initial slab, creating the adjoining tenons. Once the two pieces were joined together, any empty

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[4] Carving tools may have included small bronze pins or sharpened bone, but very little research has been done on the nature of carving tools in ancient Shang bronze casting (Thorp 2005: 143).

spaces were filled (aside from the opening) and the mold left to dry until it was time to cast (Figure 13).

5.3 Results and Discussion

5.3.1 The influence of materials on the mold-making process

During the mold-making process, the benefits of using silt-based materials became even more evident. Any attempts to use clay were rendered virtually impossible due to clay's susceptibility for rapid shrinkage and cracking. Transferring the details from the model was much easier, but the clay mold would crack almost immediately after (Figure 14). Although I attempted to replicate the entire process as laid out previously, it was simply not achievable using clay.

The silt + lime (2%) mixture was also not workable, as this amount of lime was not effective in fully binding the silt[5]. Although the small shrinkage brick retained its shape, attempting anything more complex would result in breakage. However, the silt + lime (5%) was excellent (Figure 15). This amount of lime was effective as a binder but not so much to make the recipe stiff and unworkable.

My experience with the silt + dung (2%) + lime (5%) recipe was less straightforward. When using the wet dung, the recipe took more than a day to dry into a workable texture. Even after it became workable, it was still fairly wet and fragile when shaped into a mold. However, the recipe with the solid dung material was similar to that of the silt + lime (5%). Since the dung was added as

[5] The conversion of slaked lime (CA(OH)) into calcium carbonate through the absorption of CO_2 (in the air) is necessary to fully bind the materials together, requiring substantial drying of molds before baking or carving. Time limitations prevented me from drying the silt + lime (2%) blocks for any significant amount of time; thus, it is possible that under proper conditions, this recipe would be workable.

organic material to create large voids as seen in the SEM images, rather than as a binder, it seems reasonable that primarily solid material would be added.

In two major replication projects, one conducted by the Institute of Archaeology at the Chinese Academy of Social Sciences (CASS) in 1976 and one conducted by the Shanghai Museum in 1999, the experimenters spent a great deal of effort controlling the drying effects of the clay (Li 2003: 58-76[6]). The CASS team submerged the clay in water and repeatedly kneaded it, and also added a temper of 20% sand or 30% crushed clay to reduce shrinkage. Moreover, after the mold sections were assembled, they were kept in a "controlled setting with good air circulation and constant humidity" (Li 2003: 62, citing Fugen et al. 1982). The Shanghai Museum experimenters also concluded that

> the clay mold has to be allowed to dry slowly in shaded condition to prevent uneven shrinkage and warping, while repeated patting and pounding of the mold is required during the drying process. This means that the stage of mold making, with slow drying and constant patting, takes up a considerable portion of the entire production time, about 60-70% of the total invested work hours (Li 2003: 71; citing Derui 1999: 240).

The findings of both projects serve as a significant contrast to my experiences, because they demonstrate the issues with using unprocessed loess and how their considerations differed from mine. My experiences with silt were far less arduous. By using silt-based molds with a lime binder, the drying of the recipe was not nearly as tenuous or difficult. For the most part, I was working with this material in the sun with very little cover, and the silt-based molds dried with ease. Without fear of substantial shrinkage or cracking, the decoration could be done in a variety of environments over a long period of time. The assembly of the mold pieces is also not nearly as difficult because the different sections do not shrink unevenly as they do with clay. This also has implications on the

[6] The original reports have been written in Chinese. Due to language barriers, the main source for my understanding of these experiments is from Yung-ti Li's dissertation (2003).

entire production time, as the artisans did not need to spend a significant amount of time dedicated to the drying process. Instead, the effort dedicated to the separation of the silt and clay extended the time artisans were able to spend on decoration and casting. The collection of loess and the levigation process could have also been delegated to unskilled labourers or starting apprentices, allowing the mold-makers and carvers even more time to dedicate to their specialization. Thus, when we consider the differences between the CASS and Shanghai Museum's experiences working with clay, and my experiences working with silt, the nature of the labour changes substantially because of the materials and how they were processed.

In terms of decoration, the piece-mold method seems to have had more bearing on the form of the decoration rather than the material properties. The qualities of the silt-based molds do not demand symmetry, but the formation of the vessel in consistent pieces may have encouraged symmetrical and geometric design patterns. Material properties did however have a significant influence on the ease of decoration. Transferring the details from the model to the mold was more difficult with a silt+lime recipe than with clay, and had to be touched up far more, but the molds never cracked. Carving on the silty mold while it was still wet was easier, but the molds were more susceptible to error – a slip of the hand might take off a small chunk that would not have been as detrimental while dry. Considering the time investment necessary for the elaborate detailing featured on Shang bronzes, the artisans must have carved into the molds after they had dried. However, it is possible that they took advantage of freshly removed molds to add or touch up details right away as well. Fine carvings like the *leiwen* pattern were possible but difficult, as tiny pieces would sometimes flake off. However, the material would not "catch" or "drag" on my carving tool (as it did on the clay mold), leading me to believe that the difficulty in carving can be attributable to both my lack of carving skill and the need for a finer carving tool. With a liquid dung additive, the mold material had the tendency to "drag" on the carving instrument. The solid dung material, on the other hand, did not substantially influence the ease of mold creation and decoration positively or negatively. From this perspective, the addition of dry dung is a reasonable option for added organic material.

My experience working with these materials strongly supports the hypothesis that the silt-based recipes were developed to ease the mold-making process. The piece-mold method is complex and difficult, but the structural stability of loess combined with silt's minimal shrinkage substantially facilitates mold assembly and decoration. While the levigation process is time-consuming, the resulting silt material minimizes issues presented when using clay-based recipes. The effort invested in levigation ultimately lessens the time and labour required later, allowing the artisan to handle and easily decorate the mold pieces long-term without concern for warping or shrinkage. The stability and porosity of the molds would also facilitate the actual casting itself, reducing the likelihood of a broken mold or incomplete casting.

5.3.2 Implications on a larger scale

Considering the sociopolitical and spiritual significance of bronzes during the late Shang, a great source of information about Shang society is embedded within the bronze industry. Investigating the details of its technological processes connects the industry with other facets of Shang society, and has the potential to reveal information about social structures and labour organization.

While it seems obvious that the bronze industry would have required a significant workforce, the experimental program has especially highlighted the numerous elements of the mold-making process that require considerable time and labour. The size of the industry and consistency of bronze decoration, along with the ritual function of the bronze vessels, suggests that royal involvement in its organization was likely, while further micromanagement by non-royals is certainly possible. Since the bronzes were buried in royal tombs (rather than reused), along with the sheer number of bronzes included with burials, it is also reasonable to postulate that bronzes were produced consistently. In terms of mold-making, this means that large quantities of workers would have been necessary for the regular procurement of raw materials, whether through local acquisition (loess) or travel (lime). Considering the small yield of silt after the levigation process relative to the number of molds required for a consistent bronze industry, as well as the size of some molds, daily collection of loess would have been necessary (its labour could have been shared with a ceramic industry, highlighting a cross-industrial relationship). The levigation process itself was also time consuming and would have likely required dedicated workers in order to ensure a regular supply of silt. Moreover, the labour needed for levigation without modern conveniences like reusable plastic containers and running water further emphasizes the organization and workforce required for the steady production of bronze goods.

The size of the bronze foundries, the “different groups of workers…concerned with the skilled and complex operations of mold making and of alloying and casting the metal”, and the ritual significance and output of the bronzes, all indicate that the bronze industry was undoubtedly a complex and significant entity in late Shang society (Freestone et al. 1989: 257). Investigating the technological details of the bronze casting process has thus not only highlighted the specific choices made by artisans to facilitate their mold-making and bronze casting processes, but has also further emphasized the complexity and scale of the bronze casting industry on a wider scale.

Chapter 6: Conclusion

Although it is tempting to segment and categorize different aspects of humanity, whether out of ease or epistemological tradition, as archaeologists and anthropologists we must recognize that these tend to be oversimplifications that hinder our understanding of human behaviour and culture. Humans are complex and create complex systems that react, interact and overlap with each other. While it is impossible to take every possible detail into consideration, particularly when it comes to ancient peoples, it is also helpful to recognize the categories that we have only recently developed and how these categories may hinder our understanding of past groups. Thus, this project highlights how scientific inquiry can have implications for artistic action, and how external factors (such as physical properties) can be studied alongside something as intangible as human action. Examining the ways in which technologies were developed and used, and for what purposes, for the creation of different objects (whether we would classify them as 'artistic' or not is irrelevant) is a way in which archaeologists can examine both sides of this now segregated sphere.

Integrating petrographic analysis with replication experiments was the way in which this project focused on the scientific, artistic and behavioural sides of human action in the late Shang period. By recognizing that the late Shang artisans were inevitably impacted by factors from the environment in which they were embedded, we can also recognize that technological innovations occurred because of these environmental factors alongside personal, creative and cultural elements. Quantitative analyses (such as the BSE/EDX analyses) can be coupled with qualitative research (such as the replication experiments) to enhance our understanding of human behaviour, rather than seeing these approaches as separate realms of specialization or conflicting forms of research.

Orvar Karlbeck's realization that the bronzes were cast using the piece-mold technique, as opposed to the more common lost-wax technique, was a major shift in understanding the production process of late Shang bronze casting. It had implications on labour intensity and industry organization, and the mysteries as a result of this discovery are clearly still ongoing. Karlbeck's research exemplifies the necessity of investigating technological processes because of the subsequent implications and/or information that arises from such inquiry.

This project continued this line of inquiry by looking specifically at bronze molds, the material remains of late Shang bronze-casting technology. Although innumerable studies on the bronzes themselves have led to the development of rich typologies, metallurgical inquiry, iconographic analyses, and hypotheses on their creation, it is the direct examination of molds that specifically addresses the material involved in the casting process. In particular, this project aimed to investigate how materials and their physical properties influenced and were influenced by late Shang bronze casters by experiencing the production process firsthand.

BSE/EDX analyses demonstrate a clear division between pottery and mold manufacture, highlighting specific choices by artisans, choices likely refined over generations, to achieve a desired end product. These analyses provided me with a foundation upon which I could build my experiments, which in turn allowed me to position myself, in some respects, as a mold maker with particular goals in mind. The replication experiments strongly suggested that the Shang artisans' utilization of silt alone minimized shrinkage to facilitate complex shapes and decorations. These are particular characteristics not required of other types of pottery, and represent a material engagement with the world resulting from technological action. These insights underscore the salience of Smith's understanding that "though materials are not all of technology, they have been intimately related to man's activities throughout all of history and much of prehistory and therefore provide an excellent basis for a study of some of man's most interesting characteristics under greatly different social and cultural conditions" (Smith 1970: 494).

The conclusions drawn from this project are small steps in fully understanding the late Shang bronze casting process, and there is room for much more research. Now that the purposes of a silt-based recipe are understood, further replication experiments can and should be done on a larger scale with attempts at casting a full vessel. Although my recipes were successful for small, two-piece molds, the production of large and complex molds will undoubtedly offer their own challenges.

Also, the difficulties I experienced with fine decoration suggest that research into carving tool technology is needed. The copper tools that I used, even sharpened with an electric grinding wheel, were incapable of achieving the fine and consistent detail present on late Shang mold remains. Although experience and practice are also key factors in achieving this level of skill, the manufacture of styluses from locally available material could greatly influence our understanding of mold decoration.

Finally, our understanding of voids is still limited. Due to time constraints, a thin-section was not made of the silt + dung (2.5%) + lime mold from this project. While the addition of solid cow dung did not substantially alter my molds structurally, SEM analyses of molds with dung are necessary before we can firmly assert that the voids were produced through organic additives.

There is a multitude of additional unknown elements in this complex casting process that are worthwhile to pursue, so long as we recognize that “technologies are meaningful acts of social engagement with the material world that serve as a medium through which world views, values, and social judgments are expressed tangibly” (Dobres 2000: 126). As the experiments in this thesis have shown, if we understand how artisans engaged with their craft, we can connect with their technological choices, their surrounding industry and social world, and even their physical movements. Further pursuing the technological details of late Shang bronze casting will thus continue to shed light on an industry that was politically, socially and spiritually significant during the late Shang period and will provide us with opportunities to examine the everyday perspectives of Shang artisans.

Tables and Figures

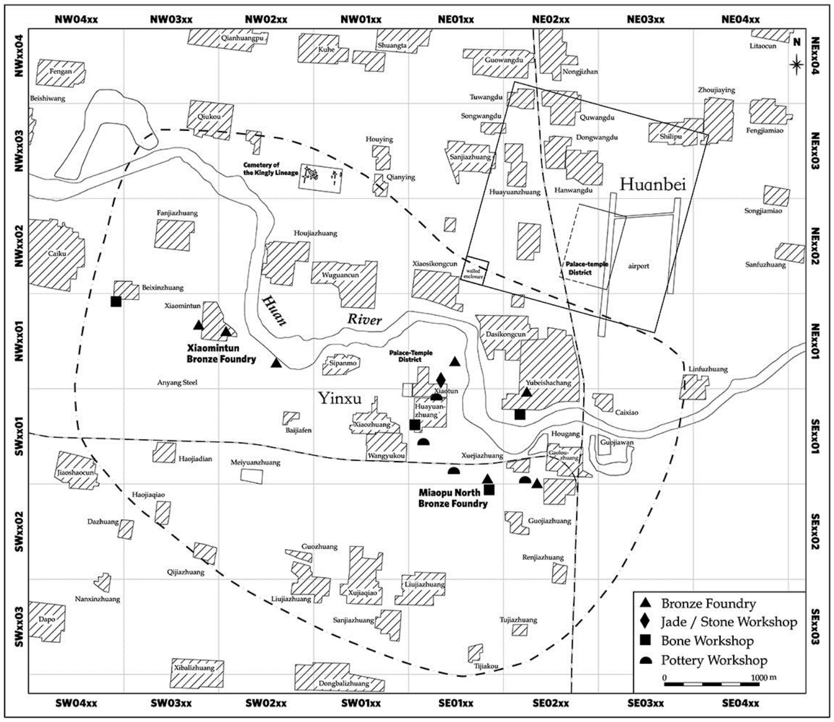
Table 1. Area percentage of voids in pottery and bronze molds.

Sample Name	Source	Type	% Voids Area
AY00-35	Liujiazhuang North	Loess (Buried A Horizon)	6.313
UBC2010-21	? Possibly non-local	Pottery	0.47
AY00-5	Liujiazhuang North	Pottery	11.07
AY00-7 location 1	Liujiazhuang North	Pottery	7.09
09AG11 location 2	Xiaomintun	Mold	24.602
09AG11 location 5	Xiaomintun	Mold	19.651
09AG14 location 1	Xiaomintun	Mold	17.98
09AG16 location 3	Xiaomintun	Mold	18.112

Table 2. Shrinkage for different mold compositions.

Composition	Drying 48 hours	Baked
Clay	4.6 mm	4.5 mm
Silt + clay	4.7 mm	4.6 mm
Silt +lime (2%)	4.9 mm	4.9 mm
Silt + lime (5%)	4.9 mm	4.9 mm
Silt + cattle dung (2.5%) + lime (5%)	4.9 mm	4.9 mm

Figure 1. Map of Yinxu.



Source: Zhichun Jing

Figure 2. Example of microstructure of unprocessed loess.
Sample AY2011-04 (unprocessed A-horizon buried loess – silt+clay, from Liujiazhuang North)
BSE working distance 7.8 mm; voltage 15kV; magnification 500x

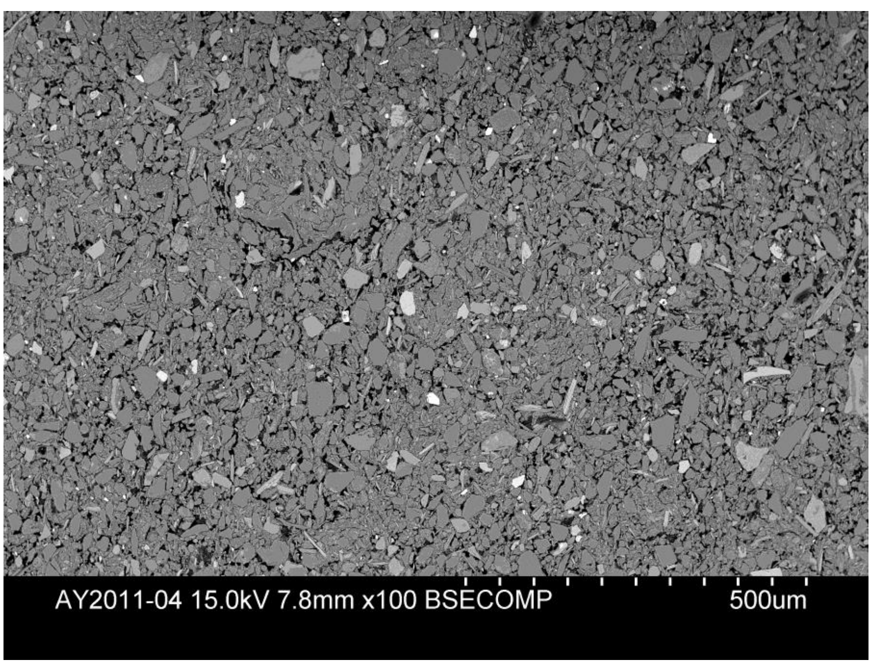


Figure 3. Microstructure of a *gui* pottery vessel – no added temper.
Sample AY00-7 (pottery, non-cooking, from Liujiazhuang North)
BSE working distance 10.7mm; voltage 20kV; magnification 100x

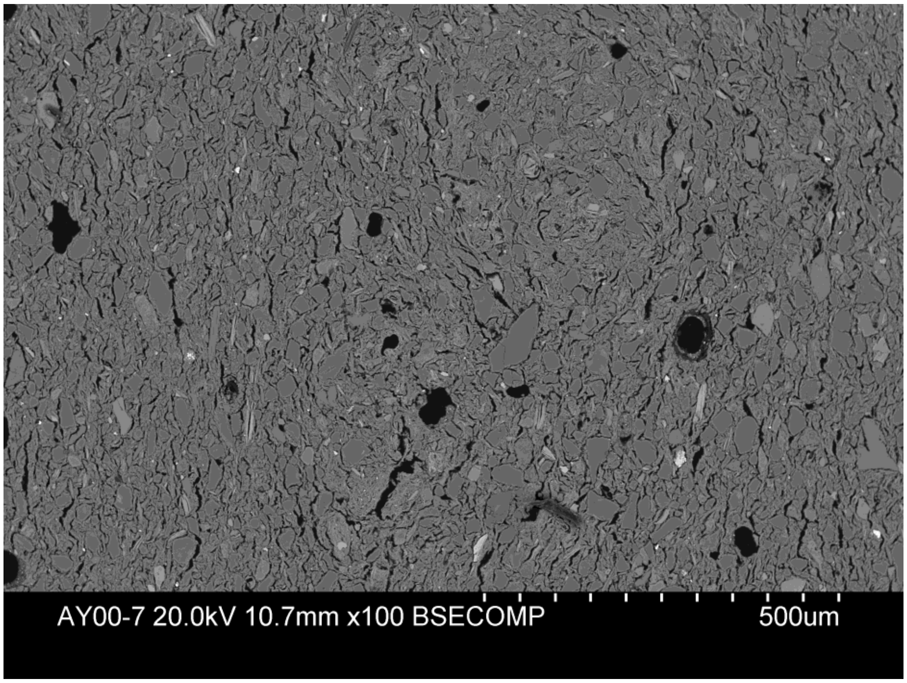


Figure 4. Microstructure of a *li* pottery vessel – sand temper.
Sample AY00-5 (pottery, cooking, from Liujiazhuang North)
BSE working distance 10.1 mm; voltage 20kV; magnification 100x

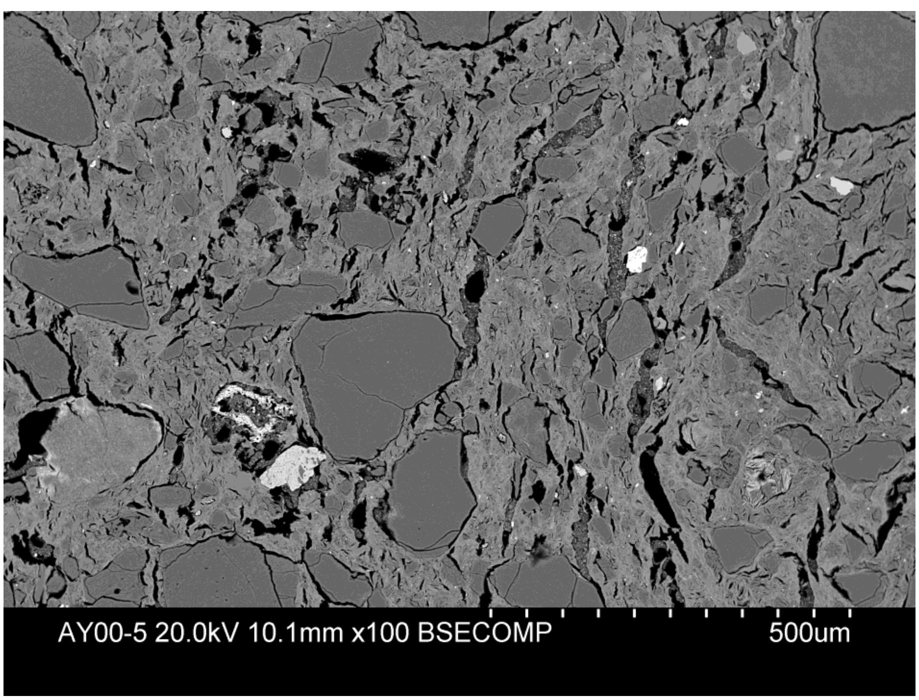


Figure 5. Microstructural comparison: bronze mold with little clay (left) and pottery with clay (right)
Samples 09AG11 (vessel mold from Xiaomintun) and UBC2010-21 (pottery, possibly non-local).
BSE (09AG11) working distance 10.6mm; voltage 20kV; magnification 500x
BSE (UBC2010-21) working distance 10.1mm; voltage 20kV; magnification 500x

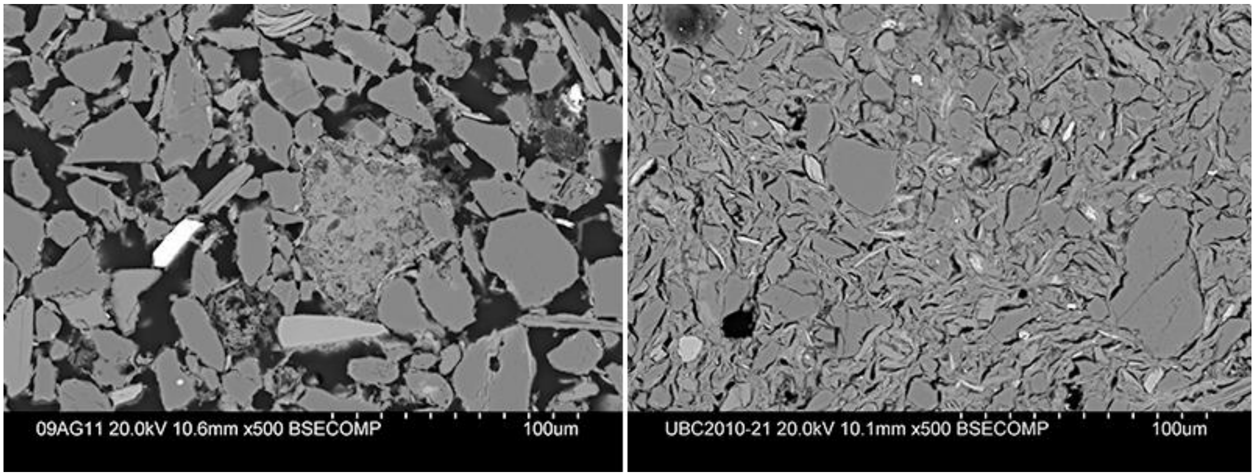


Figure 6. Elemental mapping of Ca (indicative of calcium carbonate - red) and Si (deep green – quartz; light green – feldspar and mica) in mold fragment along with Ca identification.

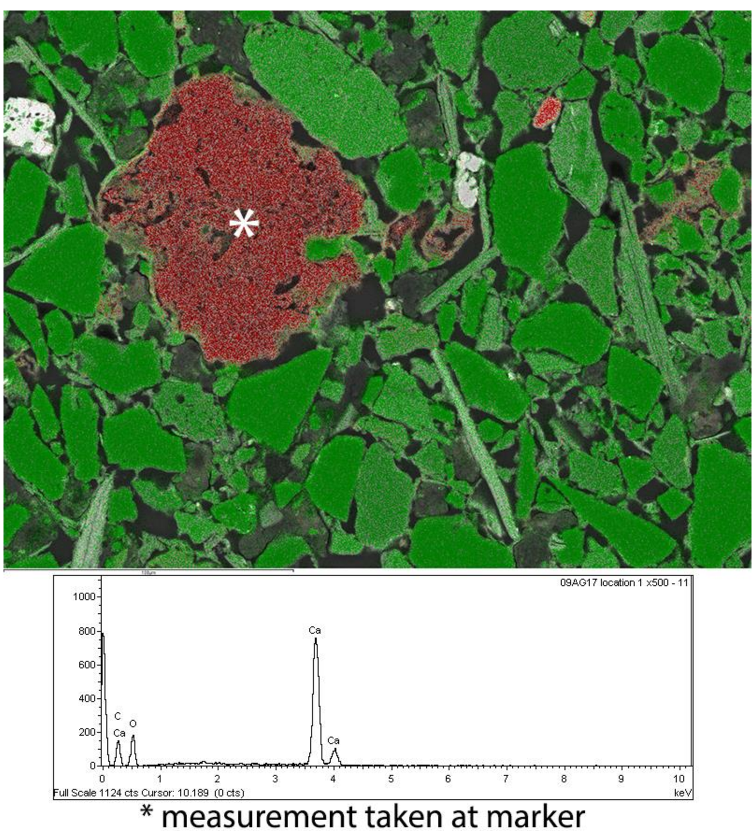


Figure 7. Elemental mapping of Ca (indicative of calcium carbonate – red) and Si (deep green – quartz; light green – feldspar and mica) in untempered pottery fragment.

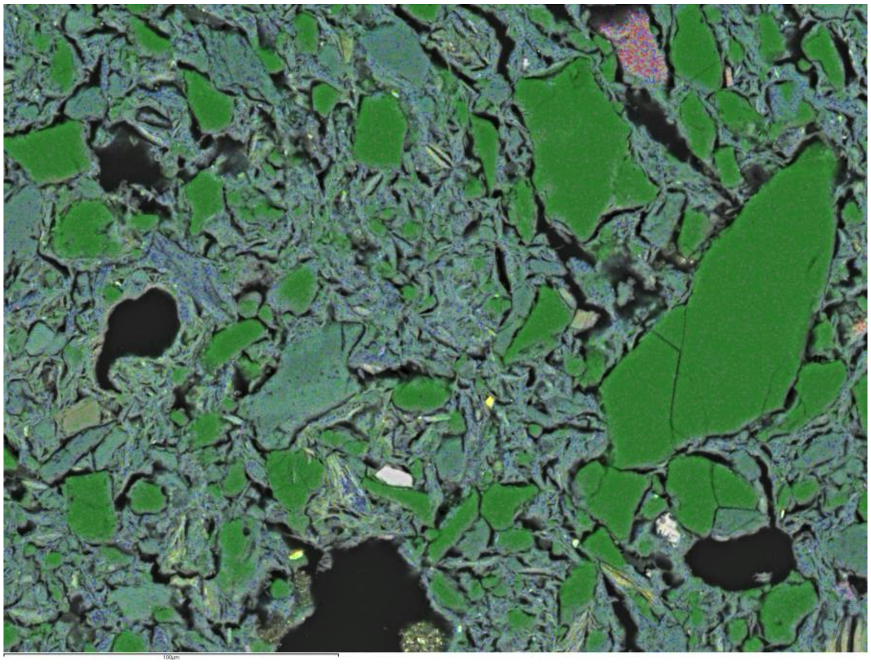


Figure 8. Elemental mapping of Ca (indicative of calcium carbonate - red) and Si (deep green – quartz; light green – feldspar and mica) in mold fragment.

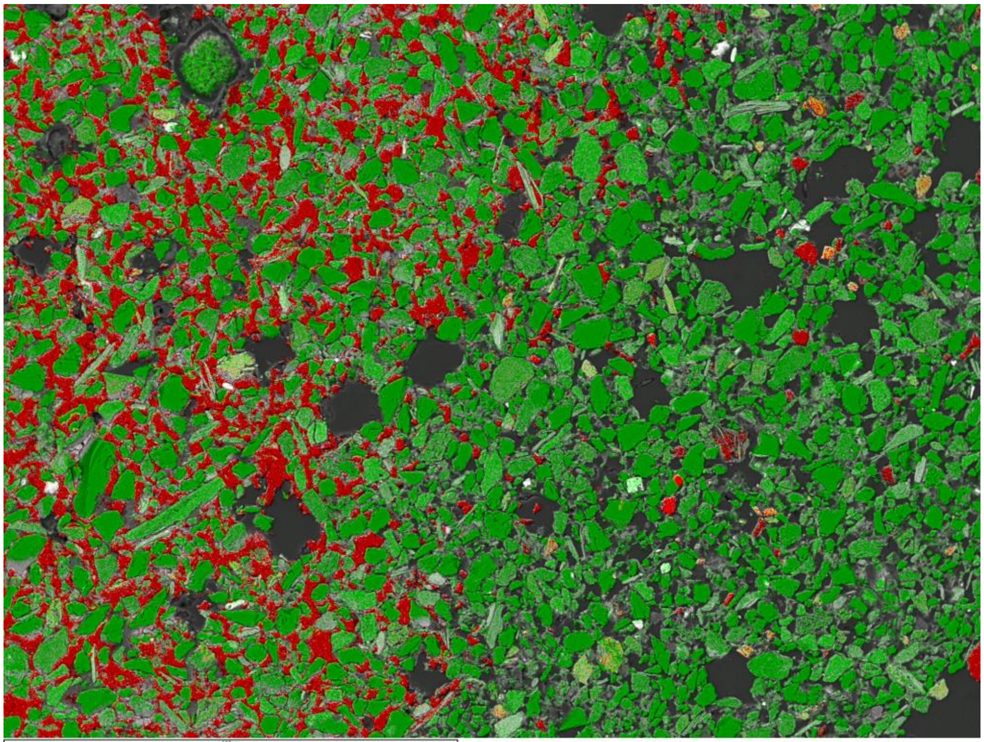


Figure 9. Adjusted threshold in ImageJ for porosity calculation.

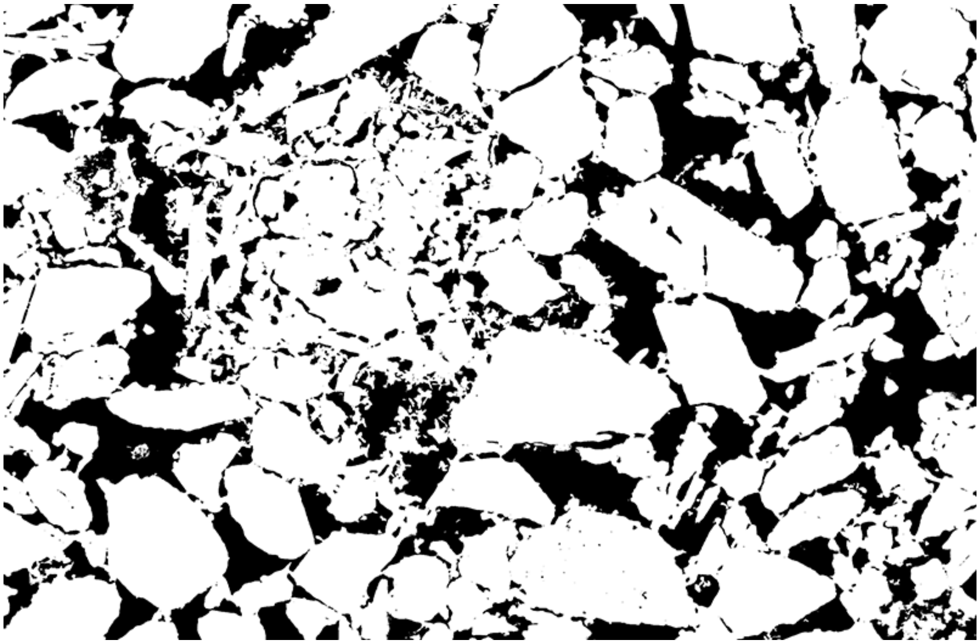


Figure 10. Carved model with *taotie* design.

Figure 11. Initial model slab.

Figure 12. Mortise and tenon (mold fragment from Dasikongcun).

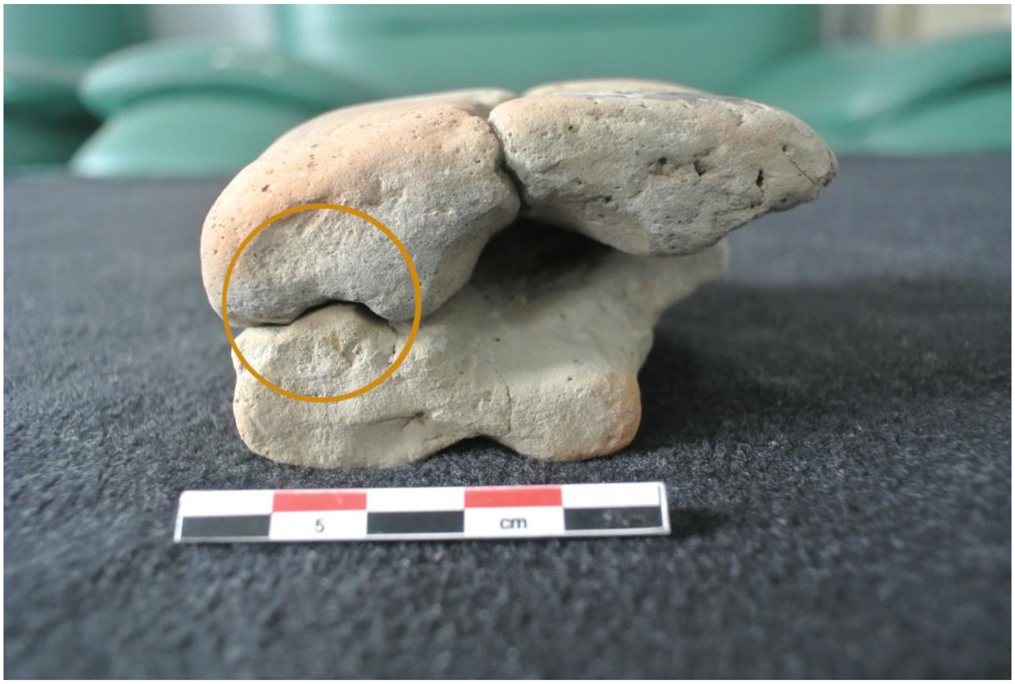


Figure 13. Completed mold.

Figure 14. Cracked clay mold.

Figure 15. Silt + 5% lime mold and model comparison. Carvings touched up on left side of mold.

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