# Mining and Smelting Technology and the Politics of Bronze in Shang and Western Zhou China: An Inquiry into the Bronze Age Interaction Sphere

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# Contents

## Figures, maps, and tables

## Abstract

In this thesis I focus on mining and smelting in China during the Shang and Western Zhou periods (c. 2200 - 770 B.C.). The importance of bronze in Shang and Zhou society and the vast quantity of bronze artifacts recovered indicates that the acquisition of metal ore would have been a major occupation of the state. The Shang and Zhou governments controlled their own bronze foundries but did not control the mines. The mines are located in southern China where the Chu state flourished during the Eastern Zhou period, likely due partly to their possession of mineral resources, and in Inner Mongolia where the steppe cultures existed. The Zhou and the Shang were likely obtaining raw materials from southern and northern cultures, either through trade or raid. Provenance studies based on chemical composition of artifact and ore will help resolve the source of Shang and Zhou ore.

## Résumé

Dans ce mémoire, je me concentre sur les activités minières et de fonderie en Chine à l'époque des Shang et des Zhou (env. 2200-770 avant J.-C.). L'importance du bronze pour les Shang et les Zhou et la grande quantité d'objets en bronze qu'on a découverts semblent indiquer que l'achat de minerai métallique était l'une des principales occupations de l'État. Les gouvernements des Shang et des Zhou contrôlaient leurs propres fonderies de bronze, mais pas les mines. Les mines étaient situées dans le sud de la Chine où le royaume de Chu fut très prospère sous les Zhou orientaux, ce qui est sans doute partiellement attribuable au fait qu'il possédait des ressources minérales, et en Mongolie intérieure où existaient déjà les cultures de la zone des steppes. Les Zhou et les Shang se procuraient sans doute leurs matières premières dans les régions du sud et du nord par le biais d'échanges ou d'incursions guerrières. Les études sur la provenance de ces objets en fonction de leur composition chimique permettront de déterminer l'origine du minerai des Shang et des Zhou.

## Acknowledgments

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# Chapter 1: Introduction

Mining and smelting in Shang and Western Zhou China is a fairly straightforward topic at first glance. When a holistic approach is taken, however, this topic extends far beyond the physical act of mining and smelting into bronze technology in general, into the significance of bronze in ancient Shang and Western Zhou society, and further into the rise of Chinese civilizations. In this vein, I use information derived from mining and smelting to study the technology of these processes, to investigate the relevance of mining and smelting in the Shang and Western Zhou bronze industry, and to discuss the rise of Chinese civilizations. Although bronze is fundamentally a technology, it was produced and used in Shang and Western Zhou society, by people under the influence of their specific socio-political, economic, and ideological frameworks.

## Technological aspects of mining and smelting

Technological aspects of mining and smelting are the easiest to study because information can be retrieved through site reports which record the structure of the ancient mines, tools found, types of ore mined, and compositional analyses of slag, etc. Technological aspects of mining that I focus on in this thesis include prospecting techniques, type of ore mined, mining tools and methods, scale of production, and the evolution of mining technology. Technological aspects of smelting include fluxing, the smelting of sulfide copper ores, and questions relating to lead and silver metallurgy. Since mining and smelting occur at the same site, I investigate the relationship between these two processes as well as the relationship between mining/smelting and founding.

## Socio-political aspects of mining

The ancient Chinese bronze ritual vessels of the Shang and Zhou periods are exquisite works of art which can be appreciated in museum collections world-wide. A great number of bronze vessels, bells, weapons, and tools have survived more than three and a half thousand years to the present day and are now artifacts that bear witness to the importance of bronze in China's first and second millennia B.C. Not only do the artifacts demonstrate a high level of technical skill and artistic ability, they also indicate the significance of bronze in Shang and Western Zhou society. The type of bronze objects manufactured, the nature of their decoration, the subject matter of their inscriptions, the context of their discovery, and the vast quantity of bronze artifacts recovered, among other characteristics, all indicate that bronze was a powerful social and political tool. Bronze was connected to the ancestors through its use in shamanistic ancestor-communication rituals, was used for the production of weapons and other implements of war, and was a precious luxury material displayed by the elite and buried with their dead.

The creation of a single bronze object involved the coordinated activity of a network of both skilled and unskilled craftsmen and workers from several areas of expertise. These included woodcutters and charcoal makers, miners and smelters of copper, tin, and lead, transporters, potters, designers, casters, and managers. Most studies concerning bronze production in ancient China focus on the final stages which occurred at the foundry. I choose to focus on mining and smelting since these steps are fundamental to bronze production. The ability to cast a bronze vessel ultimately depended on the ability to acquire raw materials. One of the main questions I address in this thesis is whether or not the Shang and Zhou states controlled the mine sites. According to K. C. Chang (1983a: 104, 1986a: 367), mines would have been under the strict control of the Shang and Zhou rulers, militia were likely posted to guard mine sites and transport routes between the mines and foundries, and the state capital was moved on several occasions in order to be closer to mine sites. In this picture, all steps in the metallurgical process, from mining through smelting to founding, would occur under the direction of the government. If the government did not control the mines, however, metal would have to be obtained from external sources, through trade or raid. The significance of bronze in ancient China, not only in the Shang and Zhou spheres of control but also in surrounding areas, suggests that such activity would surely have affected the political structure of ancient China as a whole.

## Rise of Chinese civilizations

Recent discoveries and studies have begun to stimulate changing trends in Chinese archaeology. Scholars no longer focus on the Shang and Zhou of the Central Plains as the primary and pristine state. The classical view in which Chinese civilization began in the Central Plains and then spread out to various other locations in China is now changing and attention is being paid to the possibility that the Middle Yangtze River Civilization and the Sichuan Civilization were not born out of the Shang and Zhou but developed independently out of productive Neolithic roots.

As stated above, Chang (1983a: 104, 1986a: 367) believes that the Shang and Zhou governments would have controlled mining. This is an example of the classical paradigm influencing assumptions. Since Shang and Zhou were viewed as the most civilized states and the most powerful politically, economically, and culturally, it was assumed that they would have controlled the natural resources for bronze. In this thesis I question Chang's assumption both in the light of changing trends in Chinese archaeology and also because it is an assumption which needs to be supported or rejected with solid evidence.

## Research methods

Research for this thesis was conducted at libraries of McGill University, Harvard University, and at the Freer Gallery Library in the Smithsonian Institution. I also borrowed material from libraries across North America through McGill's Interlibrary Loans department. I consulted both English and Chinese publications in order to compile a data-pool of Shang and Zhou mining and smelting. I realize that my information is only a portion of what existed in ancient times, and I am also aware that I am viewing this information through several subjective filters created when I translated original Chinese site reports, when I was assisted in translation, or when I "translated" English studies based on the original Chinese site reports. I feel, however, that I have compiled a sufficient and representative enough sample of mining and smelting during the Shang and Western Zhou periods for the purpose of this study.

The body of this thesis is divided into five main chapters, aside from the introduction and conclusion. Chapter 2 deals with a background of the Shang and Western Zhou and the importance of bronze metallurgy in the context of these political entities and societies. Chapter 3 presents a background of Shang and Western Zhou bronze production in order that the main topics of this thesis, ancient Chinese mining and smelting, may be placed into the broader context of which they are an integral part. Chapters 4 through 6 consider the three main constituents of ancient Chinese bronze: copper, tin, and lead. Within each chapter, I present ancient mining and smelting separately. Finally, I draw conclusions based on an analysis of the available data highlighting avenues of further study including issues of trade and exchange of raw materials and provenance studies. A glossary of mining and metallurgical terms and a table listing the physical properties of copper, tin, and lead are included in appendices. Tables of the characteristics of the ancient mines and compositional analyses of Chinese bronzes from the Freer Gallery are listed in the Contents.

## Chapter 2: The Shang and Western Zhou

According to traditional historiography, three dynastic periods existed in the Chinese Bronze Age before the unification of China in the third century B.C. by the Qin empire: the Xia, Shang, and Zhou. The Xia is the first legendary Bronze Age dynasty reported in texts from later periods. There is uncertainty, however, as to its actual existence. Certain strata of the Erlitou site in central Henan have been identified as the remains of a Xia city by some scholars and as the remains of an early Shang city by others. Unfortunately, there is no textual evidence at the site to clarify this issue. K. C. Chang (1986a: 315-316, 1983c) states that Erlitou will not be identified with certainty until texts are found there to match it with one of the early dynasties, although he believes that Erlitou likely represents a Xia dynasty city.

The Shang is the first period for which we have both archaeological and textual evidence relating to all major components of urbanism, such as social stratification, writing, and warfare. Data are fragmentary, however, and there is still much debate concerning many aspects of Shang society. Textual evidence includes oracle bones and inscriptions on bronze vessels, and it is thought that writing on silk and bamboo may have since perished (Chang 1986a: 296). Inscribed oracle bones have thus far been unearthed from the late Shang at Anyang, from the pre-dynastic Zhou city of Qishan (contemporaneous with Anyang), and from early Western Zhou period (G. L. Barnes 1993: 131, Shaughnessy 1985-87). These writings consist of inscriptions on sheep scapulae and turtle shells and are thought to have been used in ritual divinations in which the king asked questions of the ancestors. Inscriptions consist of inquiries and sometimes answers given. Oracle bones have been found in elite contexts, and the inscriptions concern various aspects of the king and his royal court (Chang 1986a: 298).

According to historic texts, the Zhou dynasty conquered the Shang in 1027 B.C., destroying and subjugating much of the Shang. An introduction to debate surrounding the date of the Zhou conquest of Shang may be found in Shaughnessy (1991: 217). During the Zhou period, the Zhou expanded their territory to include areas farther south than the Shang had occupied. Data from the Western Zhou are similar to those of the Shang, but also include a collection of texts. According to the Han text *Shiji*, much of the Zhou archive was destroyed by a Qin campaign to burn all historical texts which did not pertain to the Qin (Chang 1986a: 302). Also, inscriptions on Zhou bronze vessels are lengthier than those of the Shang.

Taken together, the Xia, Shang and Zhou dynasties are referred to as the "Sandai", or "Three Dynasties". Because of uncertainty as to the actual existence of the Xia, and due to the overwhelming amount of data for the Eastern Zhou period, I have primarily concentrated on the Shang and Western Zhou periods in this study, although much of what is said concerning political, social, and ideological trends may also apply to earlier and later periods. In the following sections of this chapter, I will define the Shang and Western Zhou in time and space, discuss the nature of their political systems, and indicate the relevance of bronze to politics and other areas of society and culture in ancient China.

## Defining the Shang and Western Zhou

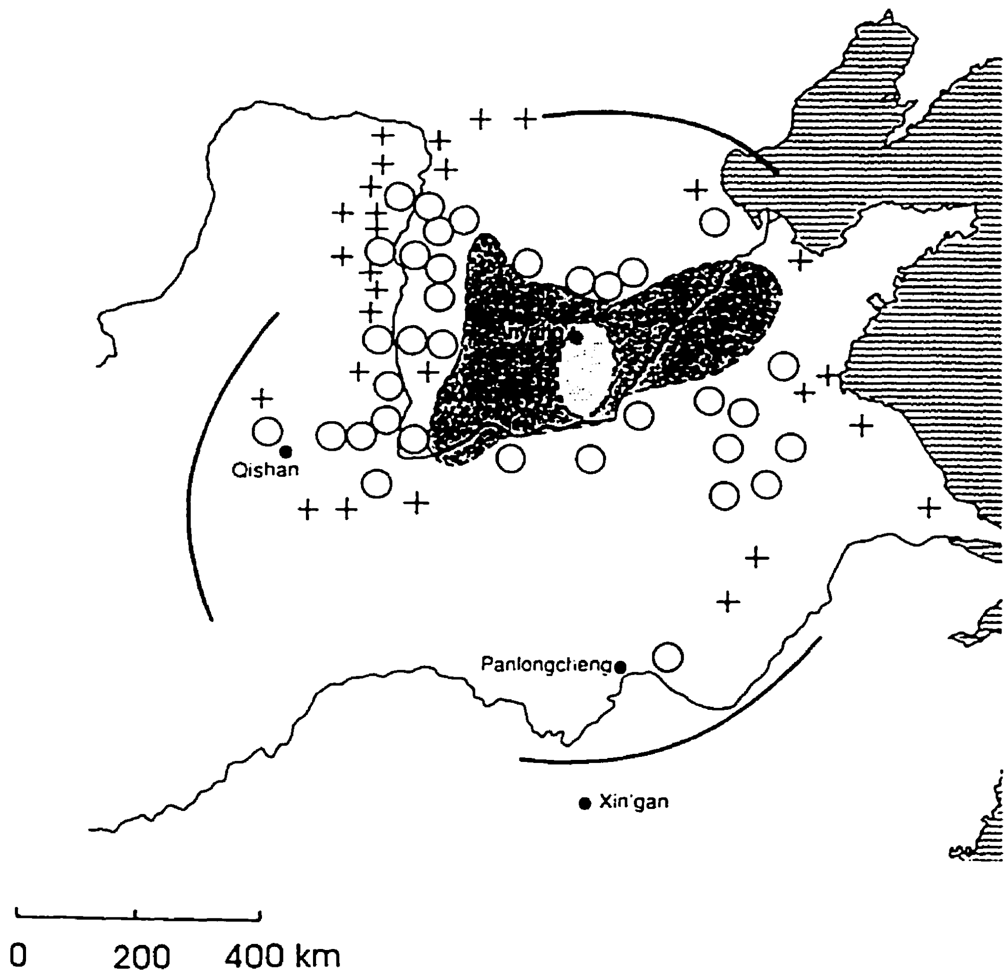
"Shang" is an ambiguous proper noun when it stands alone, for it takes on different meanings in different situations. Depending on context, the term Shang may be used to designate a specific temporal period, a geographical region, a social group, or a political system. Shang may refer to the Shang dynasty, the linear descent group of the Shang elite which ruled in north China from approximately 1750 B.C. to 1100 B.C. "Shang period" may be used to define the same temporal period as the Shang dynasty but without reference to the dynastic elite. Shang may also refer to Shang civilization, the distinctive culture of the Shang dynasty which may be identified in architecture, art, technology, burials, and ritual paraphernalia. Defined in this way, Shang remains may be found throughout China, from northern Hebei to southern Hunan and from central Shandong to central Shaanxi. In its broadest sense, Shang thus refers to Chinese civilization in general during the Shang period (Chang 1983c: 11).

In this thesis, I have mainly used a narrower definition of Shang, that which K. C. Chang (1983c: 11) refers to as the "Shang subculture". This includes the Shang state, a political system imposed on the territory of the Yellow River valley, founded by the ruling elite of a particular clan and characterized by the distinctive Shang culture. The geographical area defined by the Shang state includes the provincial areas of Henan, western Shandong, southern Hebei, northwestern Anhui, and northern Hubei (Map 1).

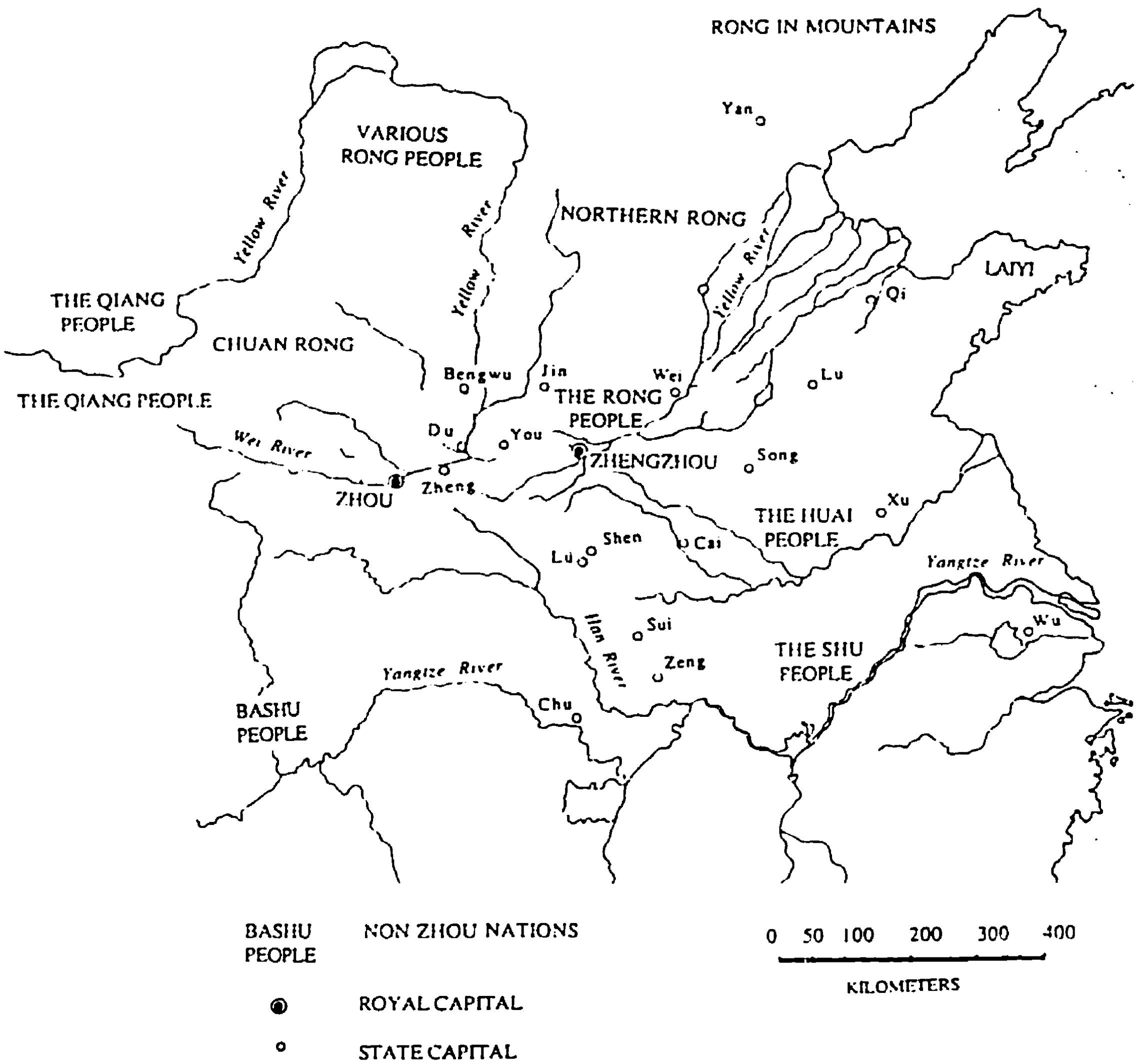
The same rationale may be applied to "Zhou". Zhou may ambiguously refer to a specific temporal period, a geographical region, a certain social group, or a political system. Thus "Western Zhou" may stand for the Western Zhou Dynasty, the Western Zhou period, or the Western Zhou subculture. As with the Shang, the definition I have used in this thesis is that of the Western Zhou subculture, which includes includes the Western Zhou state, the territory of which extends into parts of the Wei and Yangtze River valleys during the first part of the Zhou dynasty, approximately from 1100 to 771 B.C. (Map 2).

| | |
|---|---|
| Yangshao | 5000 B.C. |
| Longshan | 3000 B.C. |
| Xia | 2200 B.C. |
| Shang | 1750 B.C. |
| Western Zhou | 1100 B.C. |
| Eastern Zhou: | 771 B.C. |
| *Spring and Autumn* | |
| *Warring States* | 475 B.C. |
| Qin | 221 B.C. |

Figure 1: Timeline.




Map 1: The Shang state.
Between the nuclear Shang area (dotted) and the territories of the friendly (O) and hostile (+) lords associated with Shang is a natural buffer zone (tint) consisting of the Taihang mountains, the Huanghe Corridor, and the Yellow River flood zone.
(G. L. Barnes 1993: 133, after Chang 1980)




Map 2: The Zhou state during the Western Zhou.
(after Hsu and Linduff 1988: 15)

## Political organization

The realm of politics was crucial to the development of ancient Chinese civilization. According to Chang (1986a: 411), social stratification, a key element of civilization, was achieved primarily through political means in ancient China. These political means included kinship, the coercive nature of labor, and the control of bronze.

Kinship regulated social relations and political status in ancient China. There were likely hundreds of hierarchical kin-based clans, with members of the same clan tracing descent through the paternal line from a common divine ancestor. Those closer to the divine ancestor were in higher positions of power. Each dynasty was founded by members of different clans and each claimed divine descent (Chang 1983a: 9). Settlement patterns in ancient China show a hierarchical network of towns and villages, which may have coincided with the lineage hierarchies (p. 25). According to Chang, lineage rules were equal to laws and the lineage system was the most important social tool for controlling the populace. According to this hypothesis, the lineage laws were encoded in the rites of the ancestor cult; through ritual the leaders of the lineage enforced their authority over the lower members of the clan (p. 37).

During the Three Dynasties, coercive labor was enforced by the upper class for the production of various royal constructions (Chang 1986a: 411), including palatial foundations and walls, and semi-subterranean tombs. Labor was also applied to the production of bronze ritual objects, weapons, and tools. Although the Shang and

Western Zhou do not boast surviving monumental architecture of similar grandeur to the pyramids at Giza or at Chichen Itza, they do display a multitude of exquisite bronzes, each of which required a large and skilled labor network to create it. Keightley (1969: 56) emphasizes the large number of laborers involved in both serving the bronze foundry and working in the foundry to cast the bronze. This work force included both skilled and unskilled workers, such as miners, smelters, wood gatherers, charcoal burners, porters, and clay model makers. Keightley estimates that 500-1000 men served each foundry. The area of one of the Zhengzhou foundry sites (1,050 square meters) allows room for a labor force of 100 or more craftsmen. This estimate has been verified through calculations relating the size of bronze vessels to the capacity of crucibles unearthed at foundries. For example, a certain bronze vessel found near Anyang (the *Si mu wu da ding* vessel) weighs 875 kg. Since large crucibles have a capacity for 25 kg of molten alloy, more than 40 large crucibles, or even more smaller ones, would have been required to cast a vessel of this size. Assuming that an average of 3 to 4 men handled each crucible, at least 150 men would have worked in the foundry itself to cast such a vessel (Keightley 1969: 54, after *Wenwu* 1959(12): 27-28).

Bronze played a crucial role in the acquisition and maintenance of political power in ancient China, primarily through its use in elite ancestor rituals, as a symbol of wealth, and through its use in warfare. Thus, it is important for the purpose of this study to address the issue of politics in China during the Shang and Western Zhou periods. Due to the fact that few occupation sites other than

Anyang and Zhengzhou have been excavated and studied in detail, there is a limitation to our knowledge about Shang social and political organization and settlement patterning (G. L. Barnes 1993: 131). Thus it is not surprising that debate surrounds the issue. I have introduced several of these views concerning the nature of the political entities of the Shang and Western Zhou in order to set the stage for a discussion on metallurgy and its significant function in Chinese politics. There are several scholars' views which I have been unable to incorporate into this work, mainly those of Hsu and Linduff (1988), Keightley (1978, 1985), and Thorp (1985).

The "Sandai" or "Three Dynasties" is a traditional Chinese term used by K. C. Chang to emphasize his views regarding the rise of Chinese civilization and the nature of these political entities. Chang (1986a, 1983b) breaks with the traditional view that the Xia, Shang, and Zhou were three independent states existing in a vertical linear succession through time and separated from the rest of China. He states that archaeological evidence from the Yellow River valley from the latter part of the third millennium B.C. through the second millennium B.C. illustrates a picture of interaction. In what Chang refers to as the "Chinese interaction sphere", parallel regional cultures coexisted, interacted, and competed throughout China. Chang (1986a: 306) writes, "The Three Dynasties were probably not more than episodic hegemonies of some of the states among many, though perhaps some of the episodes were long. But each of these three states in its time was probably ahead of the others in terms of civilizational development, and there was probably a tendency during the two millennia of contending states toward the formation of increasingly larger states and thus toward the reduction of the total number of states". In this picture, the predynastic Shang would have existed contemporaneously and to the east of the Xia, and the predynastic Zhou would have existed at the same time as the Shang in the Wei-Jing valley to the west of the Shang until it had gained enough power to overthrow the Shang. Chang (1986b: x) believes that the predynastic and early dynastic Shang capital was located in the northeast, in eastern Henan or southwestern Shandong, and is yet to be found. Archaeological investigation is currently underway to find the early Shang capital, the Great City Shang (Murowchick 1996: personal communication). Chang (1986a: 361) notes that archaeological evidence from the periods of overlap during the Three Dynasties is lacking and that we will learn more about the political situation as new data arise.

According to Chang (1986a: 362), the struggle for power among the Three Dynasties was primarily a contending for political power and was not based on ethnic or cultural differences. He emphasizes that, despite details, Xia, Shang, and Zhou are variants of the same cultural theme. This is evident from the early texts as well as from the archaeological record, both in terms of material culture as well as significant aspects of cultural processes that were common to all three of the dynasties.

Chang's "interaction sphere", which gave rise to Chinese civilization in the second millennium B.C., had its roots in the Neolithic. According to Chang (1986a: 234, ch. 5), Neolithic data indicate that through time there was a trend towards wider distribution of the cultural spheres and more intensive interaction among them. Each region became increasingly complex, increasingly stratified (socially and culturally), and increasingly diversified through time, from the seventh millennium to the second millennium B.C. Chang believes that these Neolithic trends set the stage for the emergence of civilization in the Yellow River valley at the end of the third millennium B.C.

Chang (1986a: 368-408) also states his views concerning the realm of China beyond the Shang and Zhou states. According to Chang, the Central Plains area (between the Yellow and Luo rivers) is the only area in China which has literary records at this time. These texts record a unique world, in which the people of the Xia, Shang and Zhou separated themselves off from the rest of China in the Central Plains area and felt themselves superior to people of the surrounding regions. Because of this, work in Chinese archaeology and history has tended to be partial towards this area, assuming that the other regions were secondary and derivative from the Central Plains area. Developmental sequences of the outlying regions have been studied in more detail over the last decade and thus a better understanding and decentralization of the Central Plains bias has begun. Chang writes that an increasing number of areas outside the Central Plains achieved civilization-level society about the same time as the Three Dynasties. This may be questioned in light of new evidence from the Longma site in western Sichuan, dated to 2500 B.C., which I discuss below. Chang concludes from evidence such as a study of Western Zhou bronzes from regions outside the Central

Plains, that during the Zhou period there were "isolated islands of high civilization surrounded by a sea of less advanced communities" (p. 398) in the area of the lower Yangtze valley. He states that evidence indicates that some of the Western Zhou civilization-level societies of this region may have been established by an elite class who modelled their technology and social patterns after their northern counterpart. Chang states that there were still important differences between what he calls the "core" (the Three Dynasties) and the "peripheries" (the regions around the Central Plains in Shandong, eastern Mongolia and southern Manchuria, Gansu, and the lower Yangtze valley). Chang's differences include the literacy of the Three Dynasties compared with the illiteracy of the surrounding regions, the elite constructions of the Three Dynasties, the cities, palaces, royal tombs, and the degree of ritual art in contrast to that found in the regions outside the Central Plains. Chang states that by 1000 B.C., civilizations had developed in all regions and seem interrelated because of the similar material cultural in all regions, although distinct regional styles still existed (p. 409).

In a review article of Chang's (1980) book Shang Civilization, Ikawa-Smith (1980: 680) suggests that Chang's view of Chinese civilization as developing to the highest degree in northern China out of the interactive developments of several Neolithic cultures, a view he broadened from the traditional view that civilization arose specifically and discretely out of the Henan Neolithic alone, may still be too limited. She suggests that further data and future study may indicate that an even broader sphere of interaction existed throughout China, and that the Three Dynasties of the Central Plains may not have been the primary and pristine states.

Recent evidence supports the hypothesis that early Chinese civilization developed in several locations independently from that of the Central Plains. Current excavations of the Longma site in south-west China have revealed evidence of civilization in western Sichuan province. According to an article in the Asahi newspaper (October 28, 1996), the site contains a foundation, the base of which measures 60 m by 40 m. The foundation is thought to be of a ritual building. A burial found next to the foundation is thought to be a sacrificial victim. The site was dated with ceramics to 2500 B.C., which is older than the early Shang/Xia site of Erlitou. It is thought that this civilization was independent from that of the Central Plains. Excavation is being carried out by the Joint Chinese-Japanese Yangtze River Civilization, Sichuan Basin, Academic Investigation Council, directed by Mei Yuanmeng. Publications have not yet been issued concerning the investigation (Ikawa-Smith 1997: personal communication).

The Sanxingdui site is located in close proximity to the Longma site. Recent excavations have revealed that the late Neolithic culture present at Sanxingdui no later than 2700 B.C. began producing bronze no later than 1500 B.C., which is contemporaneous with the middle to late Shang. Linduff and Yan Ge (1990: 506) propose that civilization at Sanxingdui developed independently from that of the Central Plains. Although it is clear from the artifact assemblage that the Sanxingdui community was in contact with the Shang, bronze objects of a style completely different from that of the Central Plains are abundant. Bronze metallurgy at Sanxingdui was highly sophisticated, boasting the tallest bronze statue yet recovered in China. Other distinctive artifacts include bronze masks, faces, and heads, and bronze trees with ornaments of bells, birds, flowers, fruit, and animals hanging from the branches. The authors stress that the Sanxingdui site, with its advanced society, technology, and religion, is the first evidence to support the hypothesis of a multi-centered development in early China (p. 513). This hypothesis is contrary to the classical view that Chinese civilization developed out of a single monolithic source in the Central Plains.

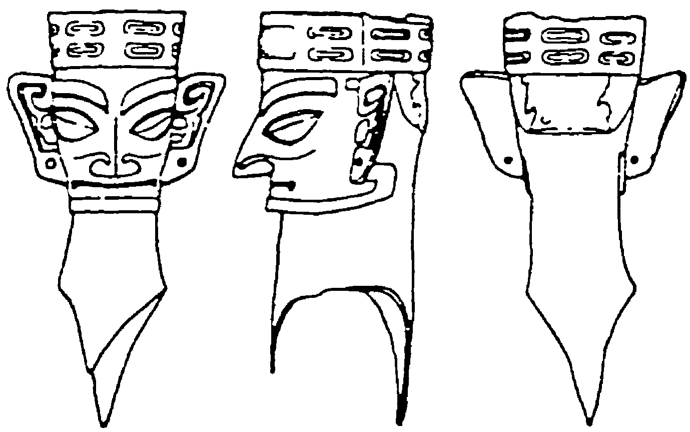


Figure 2: Sanxingdui bronze human head.
(Linduff and Yan Ge 1990: 511)

**Significance of bronze**

Bronze metallurgy was a highly significant technology in ancient China which played a major role in the emergence of states due to the importance of bronze for the acquisition and maintenance of power. The *Mozi*, a text representing the teachings of the philosopher Mozi and his disciples (c. 468-376 B.C.), contains a version of the myth The Nine *Ding* Tripods, in which passing of power from the Xia to the Shang, and from the Shang to the Zhou is described as the transfer of a bronze tripod. The bronze vessel in this myth is a symbol of the power of the state (Chang 1983a: 96). A similar version of The Nine *Ding* Tripods myth also occurs in the *Zuo Zhuan* entry for 605 B.C.

Chang points out that the Shang power structure is different than that of other states such as Mesopotamia, in which improvements in technology were used towards increasing agricultural production as the Marxist periodization scheme requires. Chang rejects the Marxist scheme, which has often been used to interpret state formation in China, and proposes instead what he calls the shamanistic worldview, in which manpower and resources were used for the production of bronze for use in ritual and war, not for agriculture and trade. Chang (1983a: 96-105, Ferrie 1995: 313-314) believes that bronze may have been the primary force shaping the power politics of ancient China. He states that the Shang competed for political power by increasing their wealth through the acquisition and display of bronze ritual vessels, which were symbols of political and religious power, and the possession of which legitimated the king's position. Chang (1983a: 108, Ferrie 1995: 314) stresses that both the archaeological and textual record testify that Shang bronze technology was used for ritual and war, the "two principal affairs of the state," as stated in the *Zuo Zhuan* entry for 579 B.C. Chang (1994b: 69) goes so far as to say that "ritual and war, as the twin instruments of political power, were the keys to the emergence of civilization in ancient China." The fact that bronze implements, such as mining tools and other implements discovered in both commoner settlements and elite tombs, are not uncommon, indicates that Chang may over-emphasize the ritual and warfare aspects of bronze while ignoring its other more practical uses (see section "Types of objects manufactured and their use").

Although social hierarchy in ancient China was based on the lineage system and one could be born into power, there were several other ways of acquiring and maintaining authority. Chang (1983a: 107) has identified a number of factors which enabled the ruling elite to access power during the period of the Three Dynasties. Most of these factors are dependent on bronze. They include status within the hierarchical lineage system, exclusive access to the ancestors through ritual and writing, military resources, the ability to control natural resources, good deeds which benefit the populace, and wealth, both acquired and displayed.

## Ritual, music, and writing

According to Chang (1983a: 63-64), the pre-Qin text *Zuo Zhuan,* third year of Duke Xuan (606 B.C.), indicates that the shaman created a link between the living and the ancestors through 'heaven-earth communication' rituals and that bronze vessels and animal offerings were fundamental ritual paraphernalia. Chang also states that the oracle bone record indicates that the Shang king was head shaman, who had powers of prognostication based on ancestral wisdom (p. 45). In this hypothesis, the animal motifs which decorate the bronze ritual vessels represent animal helpers who guided the shaman from earth to the spirit world (p. 65). Shamanism held an important role in ancient Chinese politics because access to ancestral knowledge was necessary for political authority. According to Chang (1994a: 18), during the Shang, the shamanistic act of communicating with the ancestors became monopolized by the royal house. "Shamanism thus became another tool of governing for the ruling class, along with such other tools as town walls, chariots, and shackles." Also, the fact that the animal helpers of the shamanistic ritual were represented on luxury objects (the bronze vessels) indicates that the ritual was more political than religious (Chang 1983a: 112). The inscriptions on oracle bones, another item used in earth-heaven communication, are also indicative of "shamanistic politics," as the inscriptions are of a political, and not a religious, nature (p. 110).

Bronze bells were also part of the ritual paraphernalia in Shang and Western Zhou China. Bells have been recovered mainly from elite contexts, such as tombs in the royal cemetery at Anyang, and hoards of the Western Zhou. The "Fu Hao Tomb", in its pristine unplundered state, contained an entire set of five bronze bells (Falkenhausen 1988: 86). There are numerous references to music (and dance) being used in ancestor rituals. For example, in the pre-Qin document *Chuci*, a collection of poems entitled "The Nine Songs" describes shamans dressed in beautiful regalia singing and dancing to music in order to summon the ancestors (Chang 1983a: 47). Other pre-Qin textual references to music may be found in Falkenhausen (1988: 61-77).

Chang (1983a: 88) believes that writing possessed an intrinsic power in ancient China and that writing, like bronze, was a path to authority because it was a vehicle for the living to communicate with the omniscient ancestors and thus represented ancestral knowledge. Chang suggests that both oracle bones and bronze inscriptions indicate that there were specialists who had authority to both record Shang history and predict the future (p. 94).

## Warfare

Bronze was connected with the military in Shang China in several ways. The material record indicates that one of the main uses of bronze was to manufacture weapons. Fittings for battle chariots were also made of bronze. The *Zuo Zhuan* entry for 552 B.C. illustrates the powerful using bronze booty acquired by conquering weaker rulers to cast vessels with inscriptions commemorating the event (Chang 1983a: 100). According to Chang (1986a: 366-367), contention among the various states for political dominance was a competition to gain each others' bronze ritual objects. Chang (Ferrie 1995: 314) calls the political system of ancient China, in which bronze was attained at the expense of human life to increase wealth and power, "a very cruel system".

## Natural resources

Since bronze vessels were necessary for performing high status ancestor rituals, the control of metal resources was synonymous with control of communication with the ancestors. According to Chang

(1983a: 95-97), one of the main ways of acquiring power in ancient China was by controlling the bronze resources. The *Zuo Zhuan* entry for 605 B.C. indicates that the Shang king had access to the metal resources of the various provinces under his control.

Chang (1986a: 367) proposes a hypothesis with regard to the reason for the frequent capital moves during the Three Dynasties. He suggests that the capital moves were an "incessant chase after new sources of metal" (copper, tin, and presumably lead). According to Chang, the distributions of the capital sites of the Three Dynasties coincides with the distribution of ancient copper and tin mines (fig 308, after *Wenwu* 1985(2): 65). I have not discovered evidence to support this hypothesis. All of the copper mines I have located are outside Shang and Zhou territories. To my knowledge, tin mines have not been found, likely because tin was panned from rivers and not mined (see Chapter 5).

## Wealth

Chang (1983a: 97-100) refers to the bronze ritual vessels as symbols of wealth. They were made of precious materials and thus literally were wealth, and they also displayed the "aura" of wealth. The *Zuo Zhuan* entry for 552 B.C., which describes the looting of bronze during battle for the casting of vessels with inscriptions documenting the victory, also describes the display of these vessels in order to publicize the wealth and strength of the victors and rulers. Another testimony to the bronze vessel as a symbol of wealth is the conspicuous depositing of ritual vessels and other bronze objects in royal burials in Shang China. Although most tombs at Anyang have been plundered, the tomb of the royal consort of a Shang king, commonly known as the Fu Hao Tomb, contained a lavish array of high status items including many bronze artifacts. More than 200 bronze ritual vessels, 23 bronze ritual bells, more than 130 bronze weapons, many bronze tools, and other bronze objects have been brought to light. Tombs of the royal cemetery at Anyang which have been plundered may have been even more lavish than the Fu Hao Tomb. Chang believes that the act of burying rare and luxurious items on such a grand scale suggests that the Shang elite were pointedly declaring that they were wealthy enough to dispose of precious bronze treasures.

# Chapter 3: Bronze production

Although the main focus of this thesis concerns mining and smelting in Chinese antiquity, it is important to bear in mind the broader metallurgical context into which these activities are integrated. The production of a single bronze vessel is the outcome of a long process which combines many different tasks. Copper, tin, and lead ore must be mined at different locations and with different prospecting and mining techniques. Each type of ore must then be refined into relatively pure metal at the mine site. Both refining and subsequent founding processes require fuel to feed the fires used in smelting, alloying, and casting. Thus timber must be gathered and reduced into charcoal, which in turn must be transported to both the mine/refining sites and to the foundries. The metals must also be transported to the foundries, where they are further refined, alloyed, and cast into various forms. Following casting there is the process of finishing the products.

This chapter provides a brief introduction to several aspects of bronze production which occurred at the foundries, including manufacturing techniques, alloy composition, types of objects manufactured and what they were used for, and social organization of manufacture.

## Bronze foundries

Bronze production did not occur at the mining/smelting sites, but at foundries located in the cities. Remains of bronze foundries, also known as workshops, have been discovered in several Shang and Western Zhou cities, including Erlitou, Anyang, and Zhengzhou. Evidence indicative of bronze foundry sites includes ceramic molds, models, and crucibles used in casting.

Remains of a bronze foundry were discovered at Erlitou. Within the Erlitou site, discoveries include two palatial-size foundations, dwelling foundations, human burials, pottery kilns, and a bronze foundry (Chang 1986a: 310). The nature of the evidence concerning this bronze foundry is unclear from Chang's brief description, and no further references are provided.

The Zhengzhou site, of middle Shang period age, is located in modern Henan province. Two bronze foundry sites have been discovered in the Zhengzhou area. The larger of the two (1,050 square meters) is located about 500 meters southeast of the South Gate of the old Zhengzhou city. This foundry site contained three types of crucibles, and more than a thousand fragments of clay piece molds for arrowheads, knives, adzes, ritual vessels, and small implements, the type of which is not indicated (Chang 1980: 279). Barnard and Sato (1975: 39-41) also mention that large amounts of copper ore and slag were found at this site. They propose that smelting was conducted *in situ* at this Zhengzhou foundry (after *Kaogu* 1955.3: 18-19 and *Wenwu* 1957.6: 73-74).

The second foundry site at Zhengzhou is located approximately 200 meters north of the northern city wall at an archaeological locality known as Zijingshan North. Four stamped-earth foundations were discovered, each of which was arranged according to a definite plan. Each house was rectangular with the long axis positioned east-west. Each was partitioned into two rooms, one or both of which had a door facing south, with an earthen altar against the northern wall. The floors and altars were plastered with white clay. Conical pits with "bronze-like deposits", 184 clay molds for vessels and weapons, and cores for bronze vessel legs were discovered on the floor of one of the houses and nearby outside (Chang 1980: 277). This evidence suggests that the Shang bronze smiths who occupied these sites were of a higher status than commoners, who lived in semi-subterranean houses.

Sites at Anyang, located in Henan province, likely represent the royal capital of the late Shang. Bronze foundries have been discovered in the Anyang area at the Xiaotun settlement, at the Miaobu Locus North site, and at the Xuejiazhuang Locus South site. At Xiaotun, above ground settlements which are thought to be the homes of royal family members, are associated with semi-subterranean dwellings, storage pits, and workshops. Chang (1980: 95-99, after Kuo Pao-chün 1933b) states that a major bronze industrial complex was discovered in the northern part of ground house area B-15. Evidence for founding activity includes several hundred casting molds, and several tens of crucibles. It is not clear, however, what type of foundation these remains were discovered in context with. Another "bronze-working" area was discovered nearby, indicated by ten pit houses containing many clay molds (Chang 1980: 98-99, after Kuo Pao-chün 1933a). This may have been an area where clay molds were manufactured, and not a place where the bronze was actually cast, as no crucible fragments were found there.

Barnard and Sato (1975 p. 41, after *Kaogu* 1961.2: 68 by An Zhimin) report that large quantities of slag were discovered at a Xiaotun foundry site. The authors point out that, although the presence of slag seems to indicate that smelting took place at the workshop, the absence of raw ore suggests that the further refining of previously smelted ore was taking place. The authors propose that refined materials were imported from locations outside Anyang, and were then further refined at the workshop (p. 41; An Zhimin also reaches this conclusion). Based on the absence of copper and tin in their raw material states, Chang (1980: 233) likewise concludes that smelting took place at the mine sites and not at the bronze foundries, although this does not seem to be the case for Zhengzhou, where Barnard and Sato (1975: 39-41) mention that copper ore and slag was found.

Bronze workshops were also discovered in the Anyang area at the Miaobu Locus North and Xuejiazhuang Locus South sites. The Miaobu site is located about 1 kilometer southeast of Xiaotun. According to Chang (1980: 126), it is a large and important site, likely a foundry site, in which burials, a large quantity of bronze foundry remains, ground house foundations, and storage pits were discovered. Remains of bronze founding include crucible fragments, clay molds, and clay models. Chang (1980: 126) only briefly mentions that minor excavations of the nearby Xuejiazhuang site revealed bronze and bone workshops associated with ground houses. The bronze foundries at Miaobu Locus North and Xuejiazhuang Locus South sites were possibly part of the same industrial complex.

**Techniques of manufacture**

The principle stage of bronze manufacture that took place at the foundry, that of casting, was achieved primarily through the piece-mold casting technique, a metallurgical technology unique to China. The earliest bronze vessels found at Erlitou (Xia/early Shang) were cast using this method (Franklin 1983: 95). Although there was development within the piece-mold technique, as is evident by larger and more ornate cast vessels through time, for the most part casting through the piece-mold technique remained fairly constant throughout the Bronze Age (p. 98).

The casting of bronze vessels through the piece-mold technique involves a number of steps (Chang 1983a: 105, after Li Chi and Wan Chia-pao 1964). First, a model of the vessel was created out of clay and fired in a kiln. A mold was then formed by applying a layer of fresh clay to the model. The mold was then cut into a number of pieces (the divisions depended on the nature of the vessel), and removed from the model. The mold was fired in a kiln. The core was made by scraping a layer of clay from the model, equal in thickness to the width of the vessel wall. The mold pieces were assembled around the core and either bound with rope or placed in a sand box. The molten bronze was then poured into the mold. Decoration of the vessel was achieved both through incision on the model and on the mold.

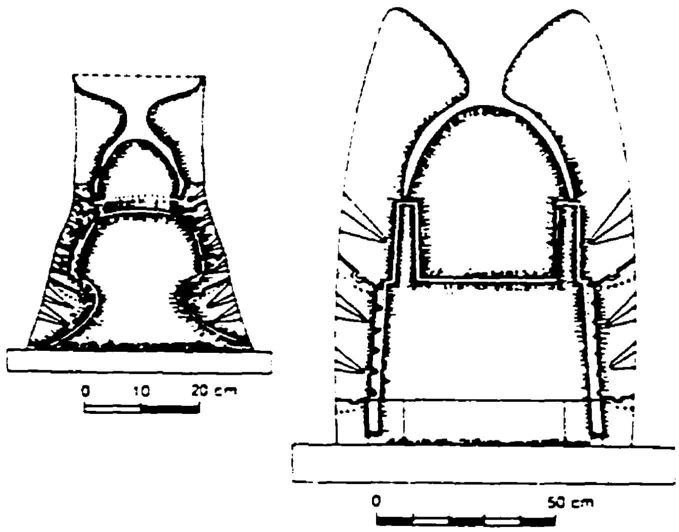



Figure 3: Clay piece-molds for the casting of bronze vessels. (Chang 1983a: 109)

There is current debate, however, as to the exclusive use of the piece-mold technique in Bronze Age China. La Plante (1988) believes that there was a phase of sheet metal working prior to the piece-mold casting of the Three Dynasties, and that the early vessels were cast with the use of a sheet metal model, instead of a clay one as most scholars assume. A sheet metal tradition would have been based on the working of metal using smithying techniques such as hammering and annealing. Although no sheet metal has been found in ancient China, La Plante uses secondary evidence to argue for its existence. For example, he suggests that individual pottery types and bronze vessel types should be specifically related in order to prove that pottery was used as a model for the bronze vessel. He demonstrates that this is not the case, showing dissimilarities between Erlitou bronzes and contemporaneous pottery found at the same site. Although there are functional similarities, pottery and bronze vessel types are significantly different in terms of style, form, and detail. La Plante also argues that the thickness of early bronze vessel rims indicates the use of a sheet metal model. The thickness of early bronze vessel rims is consistently twice as thick as the vessel walls. La Plante argues that such dimensions would occur if a sheet metal model was folded inwards on itself to make the rim. He believes that only sheet metal models could produce the thinness and angularity seen in early vessels.

Simple mold-casting was also used in China, although perhaps not at the Shang and Western Zhou urban foundries. Many stone molds used to manufacture simple tools and weapons, as well as more complex and intricate ritual vessels and halberds, have been discovered at the Wucheng site near the Ganjiang River in northern Jiangxi (Chang 1986a: 392, after *Wenwu* 1975(7): 67). The bronzes found at this site have decorative designs bearing both Shang influence and local distinctions. The stone-mold manufacturing technique as well as the design elements of the bronzes leads Chang to believe that local bronze foundries definitely existed in the area, although none have yet been found.

## Bronze alloy composition

The bronze produced in ancient China consists of a ternary alloy of copper, tin, and lead, although examples of binary copper-lead alloys have been found in Gansu province (Franklin 1985: 339), the area of China where copper first seems to have been used in the Neolithic (Muhly 1988: 14), although this is subject to debate.

Based on technical studies of bronze vessel compositions, it is clear that there was a consistent use of the ternary alloy, and that lead and tin were independent and deliberate additions (Meyers 1988: 292). The ratio of elements (copper, tin, and lead) within Shang bronzes varies with artifact type, depending on the properties required of the metal object. In China, manipulating the composition of the alloy (varying the proportions of the component metals) was used to alter the mechanical properties of the final metal product. This differs from the post-casting smithying techniques, such as hammering and annealing, which were employed by craftsmen in other metallurgical traditions such as those of Mesopotamia and Peru. There are limited exceptions in China (Franklin 1985: 339-340) and the possibility of a sheet metal phase is currently being debated. There is no sudden innovation or change of alloy type in China throughout the Bronze Age.

| Vessel type | Date | Ref. | % Cu | % Sn | % Pb | Trace elements | Total % |
|---|---|---|---|---|---|---|---|
| *yi* | Shang | 1 | 82 | 8.3 | 4.9 | Fe, Ni, As, Sb, Bi, Zn, Ag | 99.8 |
| *jia* | Shang | 1 | 95 | 0.7 | 1.5 | Fe, As, Zn, Ag | 99.1 |
| *liding* | Shang | 1 | 98 | 0.0 | 0.5 | Fe, Zn | 98.8 |
| *gu* | Shang | 1 | 82 | 12.3 | 5.3 | As, Ag | 99.8 |
| *fang ding* | Shang | 1 | 88 | 2.4 | 6.4 | Fe, Ni, As, Sb, Zn | 99.9 |
| *zhi* | Shang | 1 | 87 | 3.5 | 7.0 | Fe, Ni, As, Sb, Zn | 100.1 |
| *jue* | Sh/Zh | 2 | 65.0 | 0.0 | 33.0 | Fe, As, Bi | 98.55 |
| *gui* | Sh/Zh | 2 | 79.8 | 10.0 | 2.54 | Fe, Ni, As, Bi | 94.73 |
| *ding* | Sh/Zh | 2 | 92.0 | 0.0 | 5.00 | Fe, As | 100.3 |
| *hu* frag. | Zhou | 3 | 73.8 | 20.3 | 4.6 | | 98.7 |
| *gu* | Zhou | 4 | 63.2 | 12.81 | 12.64 | | 88.65 |
| *ding* | Zhou | 4 | 77.0 | 8.19 | 9.79 | Fe | 95.89 |
| fragment | e. Zhou | 5 | 75.8 | 13.9 | 8.8 | Fe, As | 96.8 |
| fragment | e. Zhou | 5 | 75.1 | 7.1 | 10.3 | Fe, As | 97.1 |
| fragment | l. Zhou | 5 | 61.1 | 14.7 | 16.2 | Fe, Ni, As, Sb | 93.6 |
| fragment | l. Zhou | 5 | 59.8 | 7.1 | 30.5 | Fe, Ni, As, Sb | 97.7 |
| fragment | l. Zhou | 5 | 75.7 | 13.9 | 3.1 | Fe, Ni, As, Sb | 93.2 |

References:

1: Garner (1960)
2: Umehara (1940)
3: Gettens (1951)
4: Collins (1931)
5: Plenderleith (Gettens 1969, private communication)

Table 1: Compositional analysis of bronze vessels from the Freer Gallery. (Gettens 1969: 240-241)

**Types of objects manufactured and their use**

In ancient China prior to the Bronze Age, which is usually understood as beginning with Xia or Shang, metal objects consisted of simple tools such as the awls, knives, and adzes found at Qijia sites in Gansu province (Muhly 1988: 14). During Shang times, bronze was used for the manufacture of ritual vessels and bells, weapons, and tools. By far the most publicized type of bronze objects from the Shang period is the ritual vessel. The first vessels appear in Xia/early Shang contexts (Franklin 1983: 95) and evolve both technically and stylistically throughout the Shang and later periods.

Bronze mirrors were also manufactured during Shang times; several have been found in Shang tombs, but they did not become widespread until the Zhou (Li Xueqin 1980: 68). Bronze seals (used to seal letters) also first appear in the Shang (Li Xueqin 1980: 72).

Bronze was not used for agricultural implements in ancient China. As Bray (1978: 29) explains, agricultural tools, such as the plow, were likely made of wood until the widespread adoption of iron in the sixth century B.C. Bronze is simply not practical for making heavy items that an activity such as plowing would require.

According to Keightley (1969: 57), since almost all agricultural and domestic tools were made of wood, stone, bone, and clay, it is clear that the use of bronze objects was restricted to the upper class. K. C. Chang (1983a: 108) states that the specific uses to which bronze technology was applied provide a clue to the areas of culture where natural resources and technological innovation were important. He points out that the use of bronze for agricultural tools would indicate that technology was important for the production and accumulation of wealth, but that such a use is not seen. He stresses that bronze was used for ritual objects and weapons. Chang writes, "if bronze epitomized the way in which scarce resources were used in ancient China, then political culture played a central role in Chinese civilization at its very inception."

Evidence I have encountered in this study does not suggest that bronze was exclusively used for ritual and war. Bronze mining tools, such as axes, adzes, picks, and chisels have been unearthed at Tonglüshan, Gangxia, and Jinniudong copper mines. Molds for the production of small implements were discovered at the larger of the two Zhengzhou foundry sites, and bronze tools were part of the Fu Hao tomb bronze assemblage.

Bronze was also not exclusively used by the elite. Aside from bronze tools found in the mines, bronze implements have also been found in other non-elite contexts. Chang (1980: 279) reports that small bronze tools were discovered at residential sites to the east of the larger Zhengzhou foundry. At the intersection of Longhai and Erligang roads, a cluster of residential remains was found along with storage pits, trash heaps, potsherds, stone tools, oracle bones and turtle shells, and small bronze tools. Human skeletons were found in some of the rubbish heaps. Small bronze implements were also discovered at a residential site located further to the east, on the Erligang hill.

## Social organization of manufacture

The social organization of bronze production in China may be inferred from limited evidence at foundry sites as well as from the metal objects themselves. K. C. Chang (1980: 233) states that two major bronze foundries in the Anyang area contain high-status indicators. A ground house with a rammed-earth foundation was discovered in context with clay moulds and crucible fragments. Based on the fact that such rammed-earth foundations are representative of high status residences during Shang times, Chang postulates that the Shang bronze-workers, or at least their leaders, were of higher social status than the commoner whose dwelling was semi-subterranean. Chang (1983a: 101) also uses the metal objects themselves to infer social organization. He suggests that the large size and elaborate nature of some of the vessels indicates that metallurgical production was collective and highly skilled.

According to Keightley (1969: 56), centralized management and control would be necessary to maintain the large and diverse labor force required to manufacture the bronze objects, from the wood gatherer to charcoal burner, smelter, model maker, and caster. He points out that coordinating the work of different tasks in different areas would require careful scheduling. He also suggests that those who worked at the foundry casting vessels were likely at least semi-literate, since many of the vessels contain incised or cast inscriptions. From his study of labor during the Shang and Zhou, which is based largely on inscriptional evidence, Keightley suggests that the bronze-workers were under the king's regulation, performing their assigned tasks throughout the year, and that they enjoyed a privileged status.

Franklin (1990: 23, 55) uses the physical nature of the bronze vessels to infer the social organization of metallurgy. In several studies, she has defined two broad categories of technology: prescriptive technologies and holistic technologies. Franklin defines prescriptive technologies as those which require external management and control over specialized work roles ("narrow prescriptions"), involving precision, discipline, planning, and organization. Holistic technologies, on the other hand, she defines as those which are performed by a single artisan and involve feedback and adjustment during a creative process. Examples Franklin gives of prescriptive technologies are the piece-mold bronze technology of the Shang and the machine-run factories introduced during the Industrial Revolution. Her examples of holistic technologies include stone tool making and some pottery techniques.

Franklin (1983: 97-98) views Shang metallurgy as a prescriptive process on the basis of a number of criteria. These include standardization of form and decor, incorporation of precast parts, innovation and development as experience and skill of the artisans increased, and no introduction of radically new metallurgical techniques during the Shang.

A study I conducted, based on the observation of bronzes from catalogues of exhibits in the Freer Gallery of the Smithsonian Institution in Washington, D.C. (Freer Gallery: 1946), the China Institute in America in New York City (Chase 1991), and the National Palace Museum in Taipei (1970), convinces me that there was indeed standardization of form and decor during the Shang period as well as significant innovation and development through time. Observations of two types of bronzes, the *ding* and the *jue*, which are represented from both earlier and later periods in the collection from the China Institute, show increasing sophistication and elaboration of style and form through time. Thus I support Franklin's assessment of Shang metallurgy as a prescriptive technology on the basis of the criteria concerning standardization of form and decor and innovation and development through time. If a sheet metal technique, as proposed by La Plante (1988), was used prior to and during the early Shang, however, this would imply that the Shang bronze technology became a prescriptive technology after the replacement of sheetmetal techniques with those of casting. The fact that the ternary alloy is used exclusively throughout the Bronze Age in China also supports the notion of a strictly managed industry.

Franklin (1990: 23, 55) draws social implications from defining the Shang piece-mold method as a prescriptive technology. She maintains that such a technology requires external management and control over specialized work roles and involves precision, discipline, planning, and organization. Franklin also draws more general implications from the early development of such a prescriptive technology in Shang China. She proposes that the early development of prescriptive technologies in ancient China, other forms being warp-determined textiles and certain forms of pottery, was "a formative factor in the emergence of Chinese social and political thought and behavior", including what she calls the "Chinese bureaucracy", the codes of conduct which pervade many aspects of early Chinese life, including the later imperial examination system, and the emphasis on *li*, the correct mode of conduct (p. 24). This hypothesis is limited in that it places too much emphasis on the one-way relationship of technology shaping the socio-political domain, instead of considering the mutual relationships among these realms.

# Chapter 4: Copper

Copper is the most important constituent of the ancient Chinese bronze alloy. Although it is not one of the more abundant minerals in the Earth's crust, it has been deposited in many geological formations from the time of crust formation to the present and may be found in many locations world-wide. Definitions of terminology related to copper mining and metallurgy may be found in the glossary located in Appendix 1.

## Properties of copper

Copper occurs both in the native, pure form as well as in conjunction with other elements in mineral form. There are two main classes of copper ores: primary ores, which form in igneous rocks and consist mostly of copper sulfides (West 1982: 38), and secondary ores, which form from the weathering of primary ores (sulfides) at or near the Earth's surface and consist of oxides and carbonates. Secondary ores are easily mined because they are located near the surface and are highly conspicuous due to their bright colors. The main copper ores exploited in early metallurgy include cuprite and tenorite (oxides), malachite and azurite (carbonates), and native copper (Gettens 1969: 4). Copper ores are located in most parts of the world either near the surface or at depths which require mining (West 1982: 38).

Copper has a melting point of 1083°C, much higher than that of tin or lead. Copper smelting technology, therefore, must be able to reach this high temperature. Native copper or crude copper from smelting is soft and may be hardened through smithying techniques such as hammering. Copper may also be hardened by alloying it with other metals such as tin, zinc, nickel, silver, and gold.

**Mining of copper in Chinese antiquity**

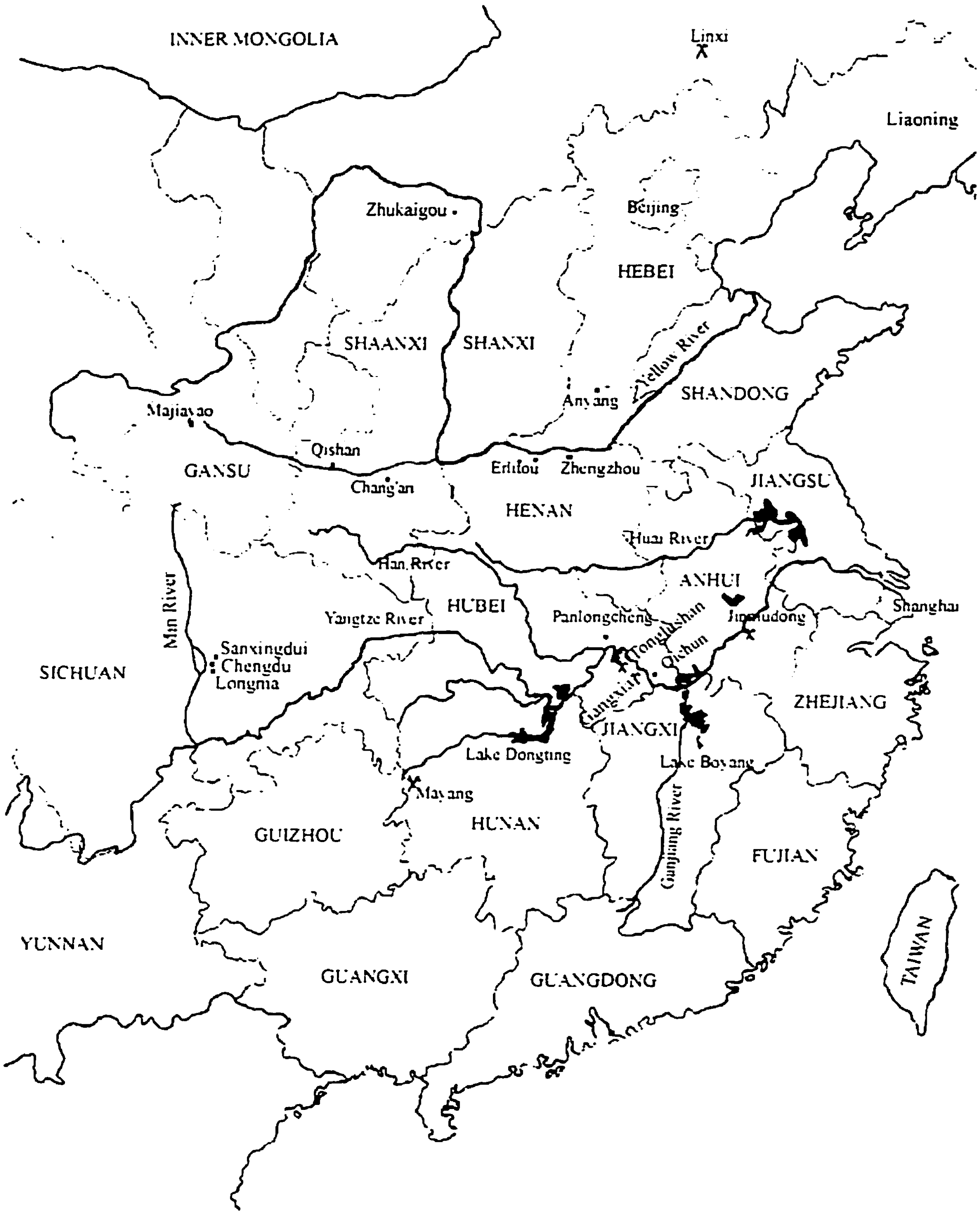
Evidence of ancient Chinese copper mining includes ancient mine sites, the majority of which have been discovered during modern mining operations. The economic position of mining in the modern world may explain why some site reports, especially those published from salvage operations, are not as detailed as might be desired (e.g. Hubei Provincial Museum 1975). It is not difficult to imagine why a mining company might ignore evidence of ancient remains in favor of continuing mining operations without interruption.

Most of the mines discussed in this section began operation sometime in the Zhou dynasty, although many of the reports use the statement "or possibly earlier" to qualify the date. This is due to the fact that often much of the ancient mine has not been excavated, or because there are mine sites in the vicinity that have been located but not explored, and thus there is the possibility that earlier remains may yet be uncovered. Also, radiocarbon dating is not always applied to the most appropriate organic material at the site. For example, at the Mayang site, radiocarbon dating was applied to a wooden mallet found in an ancient mining tunnel in lieu of the tunnel's wooden supports. The mallet may or may not have been crafted during time of mining of this particular tunnel but the wooden supports likely were (although the original wooden supports may have rotted and been replaced by later ones).

The conspicuous lack of Shang period mines may be attributed to several factors. These factors include (1) lack of reporting, (2) the possibility that Shang mines have not yet been found, (3) the likelihood that small-scale Shang mines were long ago depleted, and (4) the probability that traces of Shang mining have been erased by subsequent human or natural forces. Since mining seems to have evolved from open-pit mining during the Shang to underground mining at progressively deeper levels during the Zhou, and since open-pit mining is not easily preserved, it is not surprising that traces of the earliest stages of copper mining are not frequently found. The Linxi mine of Inner Mongolia, an open-pit copper mine dated to the late Shang period, is the earliest mine in my data-pool. Because evidence of mining activity is mainly from the Zhou, it is necessary in this study to extrapolate most mining information for Shang times.

| Mine | Initiation date | Type of ore mined | Scale of mining | Comments |
|---|---|---|---|---|
| Linxi | Late Shang | oxide + ? | ? | open-pit mine |
| Tonglüshan | Western Zhou (or earlier) | oxide, carbonate | est. 40,000 - 100,000 tons crude Cu produced | |
| Gangxia | Western Zhou | ? | ? | |
| Mayang | Zhou dynasty (or earlier) | native Cu, oxide, carbonate, sulphide (CuS) | est. 6,000-8525 tons crude Cu produced | open-pit and underground; no slag at site |
| Jinniudong | Eastern Zhou | oxide, carbonate, sulphide | est. 50,000 tons slag (exceeds Tonglushan) | |

Table 2: Characteristics of the ancient copper mines.




Map 3: Ancient China showing major archaeological sites and mine sites of the Shang and Zhou periods

Linxi copper mine

The Linxi copper mine is located in Dajing, Inner Mongolia. It was discovered in 1974 by a geological survey which revealed widespread open-pit mining (Murowchick 1989: 28-29). There appears to be some disagreement about the date mining operations began at Linxi. Barnard (1986: 35) provides calibrated radiocarbon dates which span from the late Shang to the Western Zhou period (1147 ± 119 B.C. to 840 ± 103 B.C.) (from *Wenwu* 1983.7: 138-146). Zhu Shoukang (1986) simply refers to Linxi as a Shang mine. Murowchick (1989: 29, after Wu Jiachang 1983) states that mining operations took place in the early Spring and Autumn period or earlier.

Unfortunately, it is not clear what type of ores were mined at Linxi. Malachite was found close to the mining site (Barnard (1986: 33) and iron ore was supposedly mined beginning in the Eastern Zhou (Du Faqing and Gao Wuxun 1980). Zhu Shoukang (1986: 9) mentions briefly that there was a large copper-tin deposit at Linxi.

Forty-seven separate galleries for open-pit mining have been found at Linxi (p. 9), and one has been studied in order to reconstruct mining techniques. Mining followed the ore seams which travelled at shallow depths in a sedimentary deposit. Gangue debris was piled on either side of the excavations.

More than a thousand stone tools were found at Linxi (Du Faqing and Gao Wuxun 1980), as well as wooden and bone implements, pottery, and animal bones, including sheep scapulae possibly used for divination. Slag and smelting furnace walls were also found in close proximity to the mine (Barnard 1986: 31-33). No bronze or iron tools were mentioned. This may be because bronze and iron tools were not used at Linxi or because they were removed before archaeological teams arrived.

Three dwelling remains were discovered at Linxi. These consisted of inwardly sloping post-holes in a circular arrangement with a central post. Two clusters of pits containing ash and stone tools, which Barnard (1986: 33) thinks may have been used in connection with ore refining, were found near the dwelling remains.

The Linxi site is the clearest evidence of Shang period mining that I have encountered in this study. It is probably not an accident that it is also the only exclusively open-pit mine. This supports the hypothesis that we see less evidence of Shang mining than that of later periods because the level of technology during the Shang could only handle open-pit mining, traces of which have since been obliterated.

### Tonglüshan copper mine

The Tonglüshan copper mine is by far the most famous and most thoroughly investigated ancient mine, which accounts for its prominence in this study. The ancient copper mine was discovered in 1965 at Tonglüshan during modern mining operations. Tonglüshan is located in Daye county, Hubei Province, on the southern bank of the Yangtze river in the territory of the Chu state, which flourished during the Eastern Zhou. Soil tests, artifacts, and radiocarbon dates indicate that underground mining was initiated during the Western Zhou period (Zhu Shoukang 1986: 6, Xia Nai and Yin Weizhang 1982a: 38). According to Zhu Shoukang (1986: 6), there was a "rather long period" of open-pit mining prior to underground mining. If this is true, then the initiation date of Tonglüshan may be pushed back into earlier times. Also, late Shang or early Western Zhou bronze vessels have been found in the Daye area (Chang 1986a: 406). The Tonglüshan mine was in operation until the Western Han Dynasty (Xia Nai and Yin Weizhang 1982a: 38). Pottery and smelting furnaces from the Song Dynasty (A.D. 960-1279) have been discovered, but mining pits from this time have not been found (Huangshi Museum *et al.* 1980). Reports indicate that many ancient mines are also located in the vicinity of Tonglüshan (Barnard 1986: 39), leaving open the possibility of an earlier initiation date, of later mining, as well as of a larger scale of mining. Tonglüshan radiocarbon dates are available from Wagner (1986: 3) and from the Institute of Archaeology (Beijing) (1983).

*Ore type*

The type of ore mined is an important consideration because different types of ore require different refining processes. For example, knowledge of which minerals are present in the ore is important when considering refining, for different minerals necessitate different procedures due to different silica and iron contents. An excess of silica or iron in the charge requires the addition of a flux material; the flux for excess silica is different than that for excess iron. This issue will be discussed in detail in the following section on smelting.

The copper ore mined at Tonglüshan consists entirely of oxide and carbonate minerals. A problem I have encountered with the Tonglüshan publications is that, out of six studies, only two provide the same information concerning ores mined at Tonglüshan (Barnard 1986, Huangshi Museum *et al.* 1980, Wagner 1986, Xia Nai and Yin Weizhang 1982a, Zhou Baoquan *et al.* 1988, Zhu Shoukang 1986). The only consensus on ore type among all of the studies is that native copper, malachite, and cuprite were mined. The longest list of ore minerals is given by Wagner (1986: 3, after Lu Benshan and Zhang Hongli 1984, Zhu Yingyao 1981):

chrysocolla ($CuSiO_3.2H_2O$)

malachite ($Cu_2Co_3(OH)_2$)

azurite ($Cu_3(OH)_2(CO_3)_2$)

magnetite ($Fe_3O_4$)

haematite ($Fe_2O_3$)

andradite ($Ca_3Fe_2Si_3O_{12}$, $Cu_3(AlSi_3O_{10})(OH)_2.nH2O$)

native copper (Cu)

cuprite ($Cu_2O$)

tenorite (CuO)

This seems to be the most complete list available, since each of the other lists is a subset of it. Barnard (1986: 53, from *Wenwu* 1975.2) states that the Tonglüshan ore is comprised of:

malachite ($Cu_2Co_3(OH)_2$)

azurite ($Cu_3(OH)_2(CO_3)_2$)

cuprite ($Cu_2O$)

native copper (Cu)

magnetite ($Fe_3O_4$)

haematite ($Fe_2O_3$)

Note that this list does not contain the silicate minerals chrysocolla and andradite; this information could cause a problem if used for the investigation of smelting because of the fluxing question. Murowchick (1989: 17) refrains from detailing the ore composition at all, except to say that the geology of the area is complex. Such variation in reporting seems to suggest that analysis and presentation of archaeological data have not been conducted as systematically as might be desired. Also, the practice of providing detailed references is not as strictly adhered to in the Chinese publications as it is in the West, and thus it is not always clear from where the information was derived.

*Prospecting*

Areas of dense mining activity at Tonglüshan coincide with regions of high grade ore; therefore, the prospecting method at Tonglüshan was effective (Murowchick 1989: 126). Prospecting methods included a cut and trial method, whereby vertical shafts and short tunnels were excavated in order to locate the ore (Zhou Baoquan *et al.* 1988: 126). Ore was most likely spotted by its distinctive color, and evidence suggests that the grade of the ore was determined through gravity separation techniques. According to a report in *Wenwu* (1975.2: 21), the ore body at Tonglüshan is of brilliant green, blue, and red colors mixed with red-gold and native copper (Barnard 1986: 53). Wooden boat-shaped pans found in tunnels were likely used for gravity sorting of the ore to determine its grade (Zhou Baoquan *et al.* 1988: 126). This is possible because of copper's high specific gravity with respect to gangue material. A wooden trough-shaped implement (Figure 6, no. 7) was found in an Eastern Zhou period pit in association with copper-rich dregs; it is fairly certain that it was used for purposes of gravity sorting (p. 127-128).

*Mining techniques and tools*

The underground mine at Tonglüshan consists of shafts which descend from the surface outcrop, and tunnels which extend from the shaft to follow the ore body. Through time, shaft and tunnel show enlargement in both cross section and depth (Zhou Baoquan *et al.* 1988: 126), as well as improvement in design (Murowchick 1989: 20). By the Warring States period, the overhand stoping technique was employed. In this method the tunnels slanted upwards, and the base of the ore body was mined first; during excavation gangue fell into the previously mined end of the tunnel thereby reducing the amount of waste to be removed (p. 19).

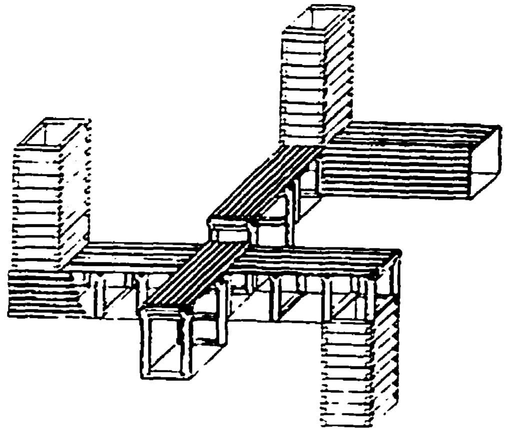


Figure 4: Structure of wooden shafts and tunnels at Tonglüshan, Warring States to Han period.
(Huangshi Museum *et al.* 1980)

At Tonglüshan, wooden tunnel-supports with mortise and tenon joints were used as supports during the earlier periods (Western Zhou and Spring and Autumn periods). Since this type of joint weakens the wood, a gradual improvement in support design occurred by the Warring States period. Tenon frames were replaced by hewn logs with flattened ends for shaft support, but the tunnels remained supported with tenon joints. By the Western Han, hewn logs with overlapping ends were used for tunnel support at Tonglüshan (Murowchick 1989: 20-21).

Hoisting of ore was achieved with a wooden windlass lifting device by the Warring States period or earlier (much rope and large hooks have been found in the earlier periods (Murowchick 1989: 23)). The windlass is part of a pulley system which enables baskets full of material to be hoisted up the shaft. A basket is tied to one end of a rope, a stone weight is tied to the other, and the rope is wrapped around a wooden axle at the shaft opening. In order to hoist material up the shaft, the empty basket is lowered and filled at some level below. The action of the falling weight pulls the basket up the shaft. Xia Nai and Yin Weizhang (1982b: 6,7) have reconstructed the windlass system.

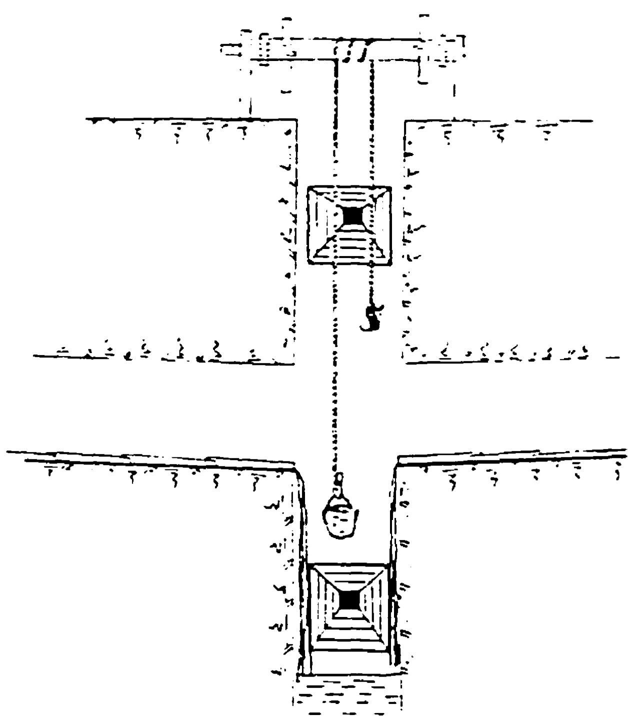


Figure 5: Wooden windlass hoisting system from Tonglüshan. (Huangshi Museum *et al.* 1980)

Ventilation of the mine occurred naturally in the earlier periods as wind swept through the tunnels. Ventilation was intentionally controlled by the Warring States period when some of the tunnels were blocked off in order to force air drafts toward working areas (Zhou Baoquan *et al.* 1988: 127). Water drainage was achieved in the earlier periods by directing water through troughs into buckets and then hoisting the buckets up the shafts. By the Spring and Autumn period, water drainage shafts were dug below the working level (p. 127).

Mining tools unearthed in the Western Zhou area of the mine include stone, wooden, bamboo and bronze tools. Wooden shovels, scoops and pans, bamboo baskets and pieces of bamboo burned at one end (torches?) were found (Murowchick 1989: 22). Small bronze axes, adzes and picks (for digging tunnels and removing ore) were also discovered (pp. 21-22). Tools for daily use, such as cups, ladles and pottery, have also been unearthed in Tonglüshan tunnels (Xia Nai and Yin Weizhang 1982a: 39). In the Eastern Zhou period larger axes were used (Murowchick 1989: 21) and iron tools were introduced by the Warring States period (Zhou Baoquan *et al.* 1988: 127). Zhou Baoquan *et al.* point out that most of the mining tools are specialized and differ from agriculture or craft tools (p. 127).

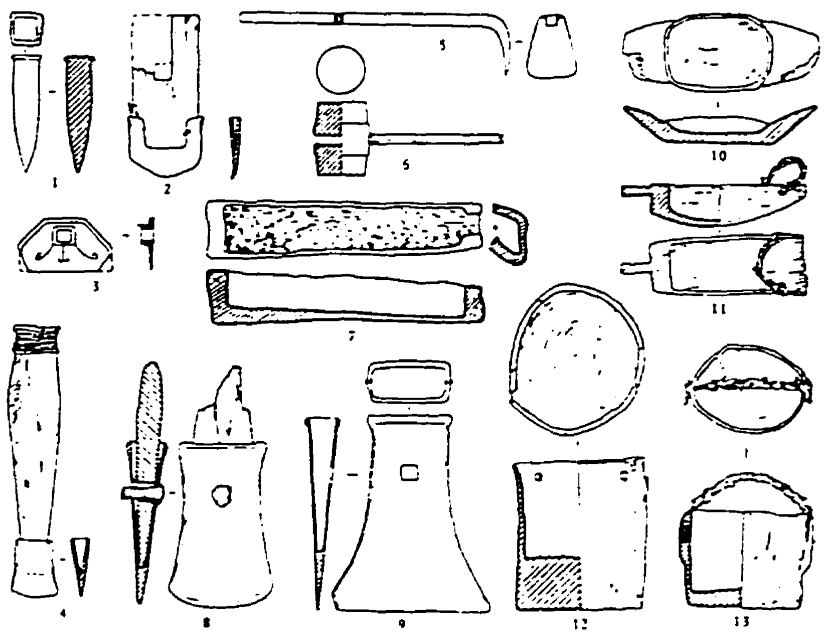


Figure 6: Mining tools discovered at Tonglüshan.
(1) Iron chisel (2) Concave iron hoe (3) Iron hoe (4) Iron axe
(5) Iron rake (6) Iron hammer (7) Wooden trough
(8,9) Axe-shaped chisels (10) Boat-shaped pan (11) Wooden ladle
(12, 13) Wooden buckets. No scale was provided.
(Xia Nai and Yin Weizhang 1982a: 39)

*Scale of mining*

Tonglüshan is the longest running ancient mine yet unearthed. It was in operation from the Western Zhou, at the latest, to the Western Han, at the earliest. Estimates of the amount of copper mined vary; for example, Wagner (1986: 2) presents two contrary estimates. Xia Nai and Yin Weizhang (1982b) calculate a total copper production of 40,000 tons based on estimates of slag quantity and percent copper in the slag. Yang Yongguang *et al.* (1980) use the same calculation method but arrives at a higher value of 80,000-100,000 tons.

*Social aspects of mining*

Social aspects of mining are difficult to infer from the available information. This may be due in part to investigative methods and concerns of the Chinese archaeologists which focus more on the technological aspects of mining and smelting than on the social aspects.

Xia Nai and Yin Weizhang (1982a: 40) state that the Tonglüshan miners' residences were likely located in the vicinity of the mine, but they have not yet been found. Not much evidence concerning social aspects of mining has been reported for Tonglüshan. Xia Nai (1975: 43) gives credit to slaves for locating and constructing the mine site at Tonglüshan. He refers to the miners as "miner slaves," but does not substantiate this claim except by providing evidence of contemporaneous slavery. The publication date of the paper suggests that perhaps the interpretation was constrained by a Marxist paradigm.

As Keightley (1969: 358) has documented, Chinese Marxist scholars tend to view data according to the Marxist periodization scheme which calls for the existence of slavery in ancient China. In this paradigm, development of civilization occurs in five stages of development from primitive communism, to slavery, feudalism, capitalism, and finally socialism. Keightley believes that neither the Shang nor the Western Zhou was a slave society. The terms "slavery" and "freedom" do not exist in the Shang and Western Zhou inscriptions and texts. Keightley states that there was no concept of individual rights in ancient China but that a natural sense of obligation existed throughout all levels of society. He admits that the lower end of the commoner class was definitely forced into "slave-like" conditions, but warns that if we are to consider this group as slaves, we would likewise need to consider all groups aside from the king as slaves (p. 378). Evidence of large-scale human sacrifice during Shang times is commonly cited as evidence of Shang slavery. Keightley objects, stating that divinations indicate that subjects and leaders of enemy states were sacrificed to the ancestors. For example, members of the Qiang tribe, nomadic pastoralists of western Henan and parts of Shanxi, were frequently sacrificed to the ancestors in numbers as large as 300. Keightley points out that slaves, who are economically productive, would not likely be sacrificed (p.369-370).

*Evolution of mining*

Since Tonglüshan has a long history of mining activity and has been studied by several scholars of early Chinese metallurgy, information is available for several time periods and we may therefore comment on the evolution of mining. Depending on the validity of the brief statement that open-pit mining existed at Tonglüshan before underground mining (Zhu Shoukang 1986: 6), mining there may have evolved from open-pit to underground. In either case, mining progressed to deeper levels through time. There was also improvement through time in shaft and tunnel construction and design, and in wooden frame construction.

It seems that there was a major period of innovation beginning in the Warring States period (Zhou Baoquan *et al.* 1988: 27). At this time, a dramatic increase in shaft and tunnel cross section is evident. This is likely connected with the increase in size of bronze tools and the introduction of iron mining tools during the Warring States period. Improvements in ventilation and water drainage systems also occurred at this time.

It would be interesting to estimate the scale of mining for the various time periods excavated at Tonglüshan to determine if there was a change in scale of production through time. Improvements in mining technology and tools, allowing for more extensive excavation and exploration of deeper levels, coupled with an improvement in working conditions, would presumably allow for greater production of copper.

Gangxia copper mine

The Gangxia copper mine is located in Hubei province only 40 km southeast of the Tonglüshan mine in Daye, also in the Chu state territory. It was discovered during local village mining, and excavations were initiated in 1986. The date of mining operations is placed during the Western Zhou period, based on only one radiocarbon date (Murowchick 1989 26, after Li Tianyuan 1988), but it is not clear how long the mine operated. Since Gangxia and Tonglüshan are contemporaneous mines located in close proximity to each other, comparative information gleaned from the available data may be relevant for answering questions concerning connections between these two mines.

The only source of information about Gangxia that I have been able to locate is Murowchick's study of ancient bronze metallurgy in southern China (1989: 26-27, after Li Tianyuan 1988). There is no information concerning the type of ore mined. Among the list of tools presented in this report, gravity sorting pans and troughs like those found at Tonglüshan are not included, so it is not clear if prospecting was performed in a way similar to that at Tonglüshan.

Mining techniques include excavation of shafts and tunnels similar to those at Tonglüshan. According to Murowchick (1989: 26, after Li Tianyuan 1988), Gangxia tunnels are irregular and may follow the higher grade ore. It is not clear what this means. Tunnel supports with mortise and tenon joints as well as hewn logs with overlapping ends were found at Gangxia. No specific dates, however, are given. At Tonglüshan, frames with mortise and tenon joints were used as supports during the earlier periods and were not replaced with the improved design of hewn logs with overlapping ends until the Western Han (p. 20-21). Gangxia may have had a better tunnel support system than Tonglüshan. If this is true, it suggests that connections between the mines were not close enough for them to concurrently share similar mining technology and that Gangxia may have influenced the introduction of the better support system at Tonglüshan. A more detailed comparative study of dates of the different types of the wooden supports would test this hypothesis.

The tools reported for Gangxia include socketed bronze axes, a serrated knife, wooden wedges, wooden shovels, and a wooden rake of interesting design (p. 27). This tool assemblage may differ from that at Tonglüshan. Shovels and axes are definitely also found at Tonglüshan; however, it is not clear that serrated knives, wooden wedges, and a unique wooden rake, are similar to tools found at Tonglüshan.

There is no information concerning the scale of mining at Gangxia and information regarding social aspects of mining is likewise lacking from the report.

Mayang copper mine

The Mayang copper mine is located in Mayang county of western Hunan province, also within the Chu state territory. Modern mining operations uncovered the ancient mine in 1979 and excavations were carried out by the Hunan Museum in 1979 and 1982. A single radiocarbon date of 780 ± 90 B.C. from a wooden mallet places Mayang in the Western Zhou and Spring and Autumn periods (Li Qingyuan and Li Zhongjun 1984). Excavators believe that the mine may have been in operation earlier than the Zhou Dynasty due to the presence of Shang period finds near the mine site in the Chenshui River area (Murowchick 1989: 28). The nature and context of these Shang period finds are unclear and thus it is impossible at this point to determine their relevance to the mine site.

Li Qingyuan and Li Zhongjun (1984) state that a river and lake system in close proximity to the mine would have placed the Mayang mine in an ideal location for trade. No slag or furnace remains have been discovered and thus it is thought that raw material was transported elsewhere for smelting.

The ore mined at Mayang consists mostly of native copper as well as the sulfide, carbonate, and oxide minerals chalcocite ($Cu_2S$), malachite ($Cu_2Co_3(OH)_2$), cuprite ($Cu_2O$) (Murowchick 1989: 27), and tenorite (CuO) (Barnard 1986: 21). This is the first mine I have encountered that contains sulfide ore; however, the simple sulfide chalcocite apparently does not require the additional smelting technique of roasting, which is discussed in the following section (West 1982: 50). Mayang is the only mine in this study for which smelting does not occur at the mine site. This unusual situation coupled with the mining of chalcocite introduces the possibility that other sulfide minerals not mentioned in the brief publications were mined at Mayang.

Mayang mining techniques include both open-pit and underground operations (Barnard 1986: 21), although I have not found detailed information concerning the open-pit mining techniques. The design of the underground mine consists of vertical shafts and irregular horizontal tunnels which follow the curving ore veins as in the other mines. Layers of ore were left untouched on the top and bottom of the tunnels. Li Qingyuan and Li Zhongjun (1984) suggest that these ore layers were of a lower grade and provided support for the tunnels. They also state that wooden supports were used in the wider spanning tunnels and at mine entrances. The wooden supports consisted of horizontal beams and vertical pillars (Barnard 1986: 22), but the type of joint used in the supports is not described, so comparison with other mines is not possible. Soot and chisel marks on the walls and ceilings suggest the use of fire setting techniques to ease the removal of ore with a chisel (p. 25). Perhaps the bamboo torches (?) found at Tonglüshan were used for a similar task.

Tools discovered at Mayang include wooden mallets, a wooden wedge, and a wooden shovel. Two iron burins and two iron mallets were discovered (Murowchick 1989: 28), but no bronze tools were reported (which does not necessarily preclude bronze from the tool assemblage). Wooden ladles and a wooden cup were also found but the context they were discovered in is not mentioned.

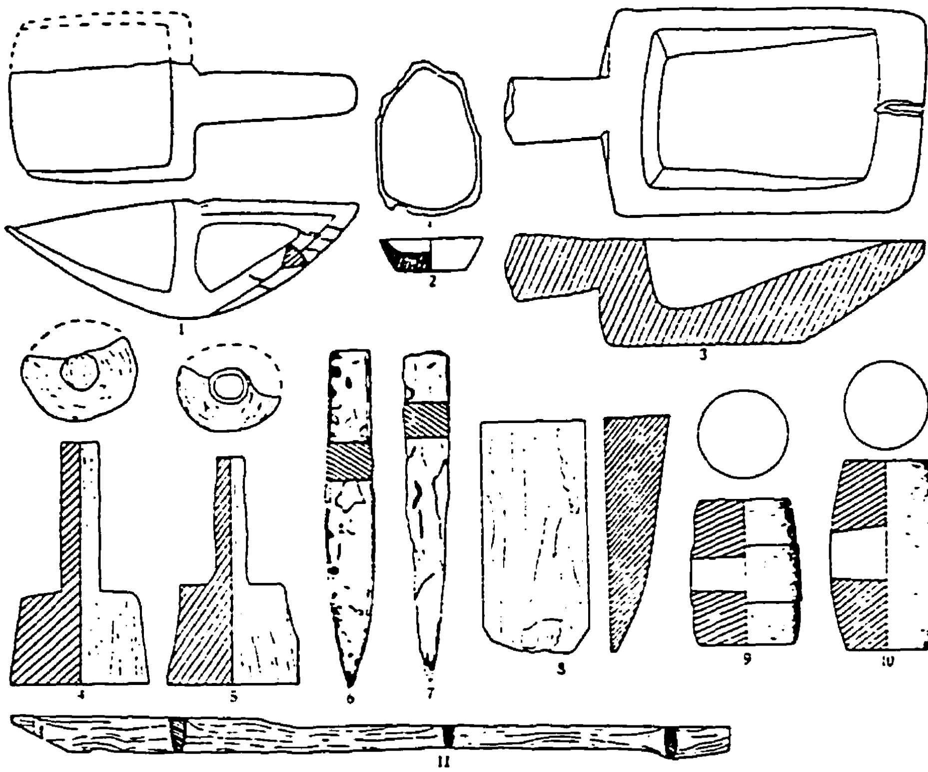


Figure 7: Mining tools discovered at Mayang

(1) Wooden ladle (2) Incomplete wooden cup (3) Wooden scoop (4, 5) Wooden mallet (6) Large iron chisel (7) Small iron chisel (8) Wooden wedge (9) Small iron hammer (10) Large iron hammer (11) Large rod. No scale was provided. (Xiong Chuanxin *et. al.* 1985: 119).

The scale of mining at Mayang has been estimated from the amount of ore removed from ancient workings, since slag is not present at the site. Differing estimates include 8,525 tons of crude copper (Murowchick 1989: 28, Barnard 1986: 22) and 6,000 tons of crude copper (Li Qingyuan and Li Zhongjun 1984). The latter estimate is based on a raw material volume that is close to 50,000 tons lower than in the first calculation. Copper production at Mayang, therefore, has been estimated at between seven and eleven times lower than at Tonglüshan.

Jinniudong copper mine

The Jinniudong mine is located near Tongling in Anhui Province. The ancient mine was discovered in 1987 by modern miners and local farmers. Unfortunately, most traces of ancient mining have been erased by the modern activity. The mine has been dated by artifacts to span from the Eastern Zhou to the Western Han dynasties (Murowchick 1989: 33-34). Over 40 mining and smelting sites have also been located in close proximity to the Jinniudong mine, possibly dating back to the Western Zhou period (p. 34).

The Jinniudong ore body consists of oxide/carbonate copper ore, mainly malachite ($Cu_2Co_3(OH)_2$), as well as sulfide ore, mainly chalcopyrite ($CuFeS_2$). This is the only instance of sulfide ore mining which would have required a different refining technique than the oxides, carbonates, and simple sulfide chalcocite. It remains to be seen, however, whether other sulfide ores were also mined at Mayang. Radiocarbon dating of the wooden tunnel supports which follow the sulfide ore in particular would be useful for resolving questions concerning the origins of sulfide ore metallurgy.

The structure of the Jinniudong mine is similar to the other mines, consisting of vertical shafts and inclined tunnels which follow the ore (p. 33). Presumably the slanting tunnels indicate the use of the overhand stoping mining technique seen in later periods at Tonglüshan. The support frames at Jinniudong are large hewn logs joined with overlapping ends (p. 34) like those found at Western Han periods at Tonglüshan.

Tools found at the Jinniudong mine include bronze chisels, iron tools (axe, hoe), and wooden implements, such as buckets, handles, a wedge, and bamboo baskets (p. 34).

Based on estimates of over 500,000 tons of slag, it appears that the scale of mining at Jinniudong exceeds that at Tonglüshan. Murowchick (1989: 34) suggests that this was a very important copper production center during the Zhou and early Han periods, and may have been connected to production at Tonglüshan.

## Conclusions

Copper mining seems to have followed the general evolution from open-pit to underground mining at progressively deeper levels through time, although remains of open-pit mining are not always present. Mining technology also follows a progressive evolution. This can be seen in improvements in shaft and tunnel design and construction, wooden support design and construction, and ventilation and drainage systems. Evolution in mining tools is also evident. In general, bronze tools were enlarged through time. Iron mining tools, which are more durable than bronze, were introduced during the Eastern Zhou.

The evolutionary trend in mining, from simple open-pit operations to complex underground mining, may explain why so little evidence of Shang mining has been recovered in comparison with that from the Zhou period. Shang mines were likely open-pit mines that have since been obliterated by natural or human forces. Evidence from the Linxi mine supports this hypothesis, because it is the only exclusively open-pit mine as well as the only clearly Shang period mine.

## Ancient copper refining - background

Refining technology consists of a series of steps through which copper metal is extracted from the fragments of mined material. These steps include crushing of the ore-containing rock, selection of high-grade pieces, smelting of the ore, roasting of certain types of ores, and casting the crude copper into ingot form for transport to the foundry. Smelting is the main step in this process, simply stated as the melting of the ore at high temperatures in a furnace.

### Origins

Dates for the earliest copper smelting in China vary. Depending on the authenticity of these finds, the beginnings of copper smelting metallurgy in China may reach back into Neolithic times. It may seem like a contradiction in terms to discuss early copper metallurgy of the Neolithic period. There is no need, however, to redefine the beginning of the Bronze Age, which is commonly placed at the beginning of the Xia or Shang period, or to introduce the term Copper Age, based on limited and isolated finds of small quantities of copper. As G. L. Barnes (1993: 119) points out, the mere existence of small quantities of metal did not change the character of Neolithic society.

Bagley (1987: 16) places the earliest copper metallurgy, with both smithying and smelting techniques, at Neolithic Qijia sites (Qijia culture sites generally fall into the latter part of the third millennium B.C. (Chang 1986a: 282)). Zhu Shoukang (1986: 2) states that the earliest known bronze knife in China comes from the Majiayao Culture of the Neolithic period in Gansu province, with a date of c. 2750 B.C.; residues of metallic copper (as opposed to native copper), malachite, and limonite (copper ores) were also found at this site. Zhu also states that slag dating to 2350 B.C. has been discovered in Huaiyang County of Henan and that smelting furnaces dating to earlier than 2000 B.C. were also unearthed in Henan (after Li Jinghua 1985). Zhu also mentions that a bronze *gui* vessel fragment comprised of copper, tin, and lead, with uniform wall thickness, was unearthed at Wangchenggang, a Longshan site in Henan dated at 1850 B.C. K. C. Chang (1986a: 274), however, only briefly mentions this artifact as a possible fragment of a bronze *gui* tripod, and provides the references which claim that it is (*gui* references: Li H. T. 1984: 2, *Wenwu* 1983(3), pl. 1).

Oxides and carbonates versus sulfides

The refining process, during which copper is extracted from the ore, differs depending on the type of ore. Oxide and carbonate ores are the simplest to refine for they only require smelting. Sulfide ores, on the other hand, require additional steps of roasting (Muhly 1973: 171-172, Tylecote 1980b: 5).

This disparity in the refining process between oxide/carbonates and sulfides is significant in that it may provide clues to the degree of comprehension of smelting knowledge grasped by the ancient artisans. We should not hastily assume that early metallurgy was not advanced enough to handle sulfide smelting requirements. Early Chinese metallurgy of the Shang period already demonstrates an impressive level of technical ability, and sulfide smelting is not as highly complicated as some scholars suggest. It merely requires an additional step or two of roasting in the hearth of an open air fire. Muhly (1973: 172) states that it was once a common belief that only oxide/carbonates were smelted in the earlier days of copper metallurgy, and that sulfides were not used until Roman times in Europe. He states that it is evident that sulfides were being smelted as early as the fifth millennium B.C., but without the additional refining requirements. Because the sulfur was not released in a roasting step (see *roasting* section below), the copper in this material, referred to as a matte, was contaminated with sulfur. Muhly suggests that this is the material referred to in Old Assyrian and Greek texts as "black copper". He also states that sulfides were in general use by at least the second millennium B.C. and that sulfide mining on Cyprus extends back into the third millennium B.C. It is thus possible to determine whether roasting was understood through compositional analysis of copper and possibly of bronze (p. 352 no. 7, 8).

Rutherford Gettens, the technical analyst for the Freer Gallery, presents a similar picture of assumptions commonly held about the origins of sulfide mining and smelting. He states that there is a common assumption that sulfides were not used until the time of the Romans in Europe because they are difficult to recognize and smelt. To contradict this belief Gettens points out that pre-Columbian metallurgists in Peru smelted sulfide ores (Gettens 1969: 4). Personal experience in underground sulfide copper mines has demonstrated to me that sulfide ores are not difficult to recognize. They are highly reflective metallic-colored ores which contrast greatly with the dark opaque gangue that surrounds them. They are similar in appearance to native ores but may be distinguished on the basis of their brittleness (Pough 1983: 80). Sulfides are also physically associated with their weathering products, the brightly colored oxide/carbonates which outcrop at the surface. Thus there is a physical spatial connection between the two ore-types as well as a visual connection in that both oxides and sulfides are bright or shiny and conspicuous against neighboring opaque rock. Prospecting for sulfides is not, therefore, a great intellectual leap from prospecting for oxides.

Zhu Shoukang (1986: 7, after Zhang Jingguo *et al.* 1985) states that the smelting of sulfides occurred quite late in China, citing 'recent' excavations which revealed an ingot produced by the smelting of sulfide ores during the Eastern Zhou period in Guichi County of Anhui Province. He also cites a sulfide mine of the Eastern Han Dynasty (p. 7). Murowchick (1989: 13) refers to the refining of sulfides as a complicated method of metal extraction which was known in China since the Han Dynasty and since the third millennium B.C. in Cyprus.

Evidence from this study suggests that sulfides were possibly smelted during the Western Zhou period at Jinniudong and possibly even at Mayang.

According to a study conducted by Tylecote (1980b), elemental analysis of copper ingots can reveal whether they were smelted from sulfides or oxides. During Tylecote's experimental smelting of oxide copper ore, some of the minor elements (arsenic, antimony, bismuth, lead, etc.) were partitioned into the copper resulting in a contaminated copper ingot. The experimental smelting of the sulfide ore, with its additional step of roasting, on the other hand, resulted in a purer copper, since most of the trace elements were lost into the slag during the two heating steps (Tylecote 1980b). It still remains to be seen whether the analysis of Chinese bronze, with a more complicated chemical history than smelted copper, can also reveal which type of ore was smelted.

The refining of sulfide ores relates to mining technology, since sulfides occur at deeper levels of the ore body, while their oxide/carbonate weathering products tend to be found near the surface. In this way the evolution of mining, from open-pit to underground mining at progressively deeper levels, relates to the evolution of smelting knowledge, from oxide/carbonates to sulfides.

The question arises as to whether knowledge of sulfide smelting originated through experimentation and invention based on principles of smelting oxide/carbonate ores, through application of lead sulfide metallurgy which may have originated prior to copper metallurgy (see the chapter on lead for more details), or as a result of the introduction of knowledge from external sources.

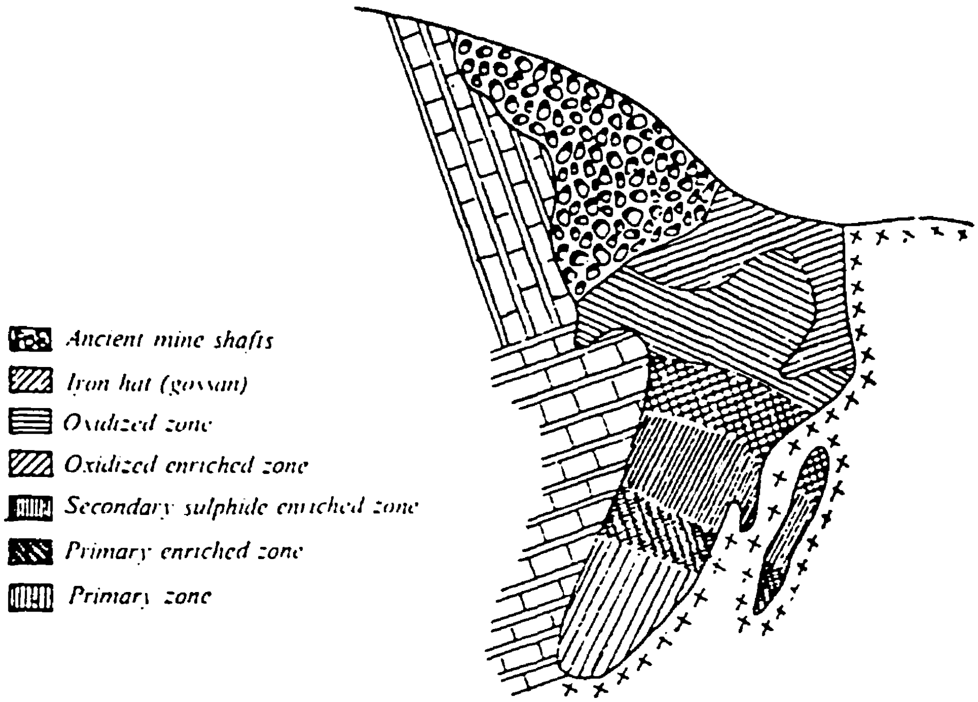



Figure 8: Cross section of the ore-body at Tonglüshan showing location of oxidized zones in relation to the sulfide zones. (Wagner 1986: 2, after Xia Nai 1982a: 2)

<u>Copper smelting sites in ancient China</u>

In ancient China copper smelting usually took place at the copper mine sites. The notable exception is the Mayang mine site, where no smelting remains have been found. Smelting may have been performed at mine sites because the smelting process is relatively simple to set up and carry out and it is much easier to transport copper ingots (smelted copper cast in a mold) than to transport the raw material with its useless and heavy waste material. K. C. Chang (1980: 233) states that no copper or tin ores are found at Shang workshops and that smelting was done at the mines; he also predicts that we may find bronze workshops at some of the Shang mine sites. I have not come across any evidence of this. As previously mentioned, smelting evidence has been reported at a Zhengzhou foundry site.

Most data on smelting come from the Tonglüshan mine. Although the mine has an initiation date of Western Zhou or earlier, the excavated smelting sites are dated from the Spring and Autumn period. Three smelting sites and over ten furnaces have been excavated (Zhou Baoquan *et al.* 1988: 128), and more than fifty smelting sites have been identified (Wagner 1986: 2). It is not clear whether the furnaces date to a later period than the mining activity because earlier ones have not yet been located or studied or because smelting activity was initiated at a later date than mining. This would be an interesting line of inquiry in terms of the relationship between mining and smelting and the origins of these bodies of knowledge.

There is no evidence for smelting at the Mayang mine. Li Qingyuan and Li Zhongjun (1984) postulate that the raw material was transported via river to nearby smelting sites.

In the single report that I have acquired for the Gangxia mine, there is no discussion of refining activity, or lack of it, at that mine.

Evidence for smelting at Linxi includes a great quantity of slag, walls of smelting furnaces, and two clusters of small pits containing ash and stone tools. Barnard (1986: 33) suggests that these are connected with the ore-refining process, perhaps for roasting of the ores. Unfortunately, I have not found documentation concerning the type of ore mined at Linxi.

**Ancient copper refining - the process**

Crushing and selection

The first step in ore refining is to crush the chunks of mined ore into smaller pieces in order to select pieces of higher grade, thereby minimizing the amount of gangue and maximizing the amount of copper ore. At Tonglüshan a flat stone hammering block on which ore was crushed was unearthed near a furnace at Site No. 6 (Huangshi Museum *et al.* 1980, Wagner 1986: 6). Xia Nai and Yin Weizhang (1982a: 40) suggest that stone hammers and balls found at Tonglüshan smelting sites were used for the purpose of ore crushing. Bits of ore of uniform size were also found in shallow holes at the smelting site.

Selection of pieces that were richer in copper ore was likely done through handpicking and gravity selection (Zhou Baoquan *et al.* 1986: 127). Handpicking was probably based on color since many of the ores are distinctive in color (Murowchick 1989: 35). Gravity selection operates on the principle that copper has a much higher specific gravity than gangue. A wooden trough discovered in a pit from the Eastern Zhou period is thought to have been used for gravity sorting of high grade ore. The trough has an opening at one end which is narrower than the other, and appears to be slanted in the direction of the narrow end (Figure 6, no. 7). The trough was discovered in association with dregs containing 12-30% copper (Zhou Baoquan *et al.* 1986: 127-128).

## Roasting

As discussed above, roasting is a stage in the refining process which is necessary for most sulfide ores, such as covellite (CuS), chalcopyrite ($CuFeS_2$), and pyrite (FeS). According to West, chalcocite ($Cu_2S$) does not require roasting (West 1982: 50). Roasting the ores in the coals of an open air fire eliminates much of the sulfur content as sulfur is converted to sulfur dioxide and is released as a gas. The ores may then be smelted in the same way as oxides. If the sulfur is not sufficiently released then the resulting product of the smelt will be impure, what is referred to as a matte. This matte requires additional roasting and smelting (Tylecote 1980b: 5), unless it is to remain in the contaminated state. It is not yet clear whether matte artifacts have been unearthed in China.

In modern ore refineries a ventilation system is required to remove the sulfuric gas, which is an air pollutant. At Sudbury, Ontario, sulfur pollution accounts for the black coating on surfaces near the mine. A high smokestack was erected in order to carry the fumes away from Sudbury; unfortunately, sulfur pollution still descends in the form of acid rain. Sulfur pollution may have been a problem in Chinese antiquity as well in areas where sulfide ores were roasted.

## Smelting

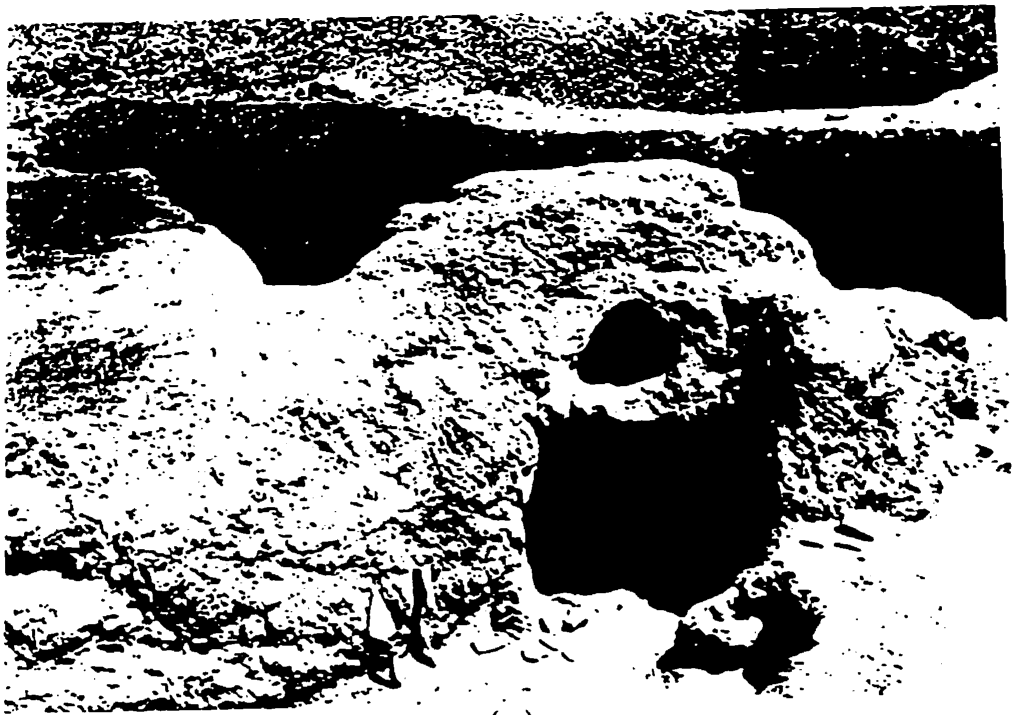
Smelting is the process which actually separates the copper from the surrounding material. This is carried out by melting pieces of ore in the reducing environment of a furnace in the presence of carbon (which is present in charcoal and coal). During reaction, the carbon combines with oxygen to produce carbon-dioxide gas and impurities form a slag on the surface of the molten copper (Muhly 1973: 171). Through a door in the furnace these impurities may be scraped off and the crude copper may be tapped out.

### *Flux*

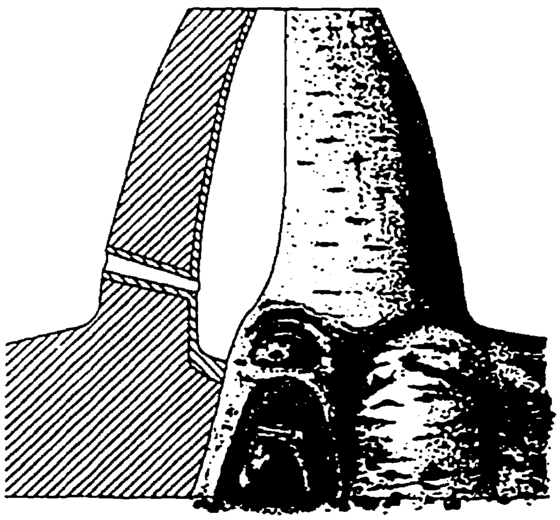
The addition of material referred to as a flux facilitates the separation of metallic copper from gangue material. In a series of experiments on ancient copper smelting of oxide ores, Tylecote and Boydell (1978: 15) have shown that without the addition of a flux most of the copper does not separate out. This holds true for both oxide/carbonates and sulfides, the difference being that different materials are required as a flux in each case. Tylecote (1980b: 5) explains that siliceous ores, which contain an excess of silica, require the addition of an iron-oxide (such as haematite). Ferruginous ores, which contain an excess of iron, must be fluxed with silica. In general, sulfides are ferruginous and oxides are siliceous. Only "pure" minerals such as cuprite, malachite, and chalcocite can be smelted without fluxing (note that chalcocite does not require roasting as well). Tylecote demonstrates experimentally that adding a flux to silicious or ferruginous ores is absolutely necessary, for his experimental smelting of both oxide and sulfide ores without the addition of a flux resulted in failure and virtually no copper was reduced. He suggests that ancient smelters probably determined whether to use sand or iron oxide by trial and error.

*Furnace*

Partially preserved furnaces have been discovered at Tonglüshan. Slag, fire-resistant materials, ores, charcoal, and a few lumps of crude metal were associated with a furnace dating from 800 B.C. The furnace walls were constructed of refractory materials such as red clay, kaolin, quartz sand, pieces of igneous rock, and iron ore dust. The base of the furnace consisted of a hollow space supporting the hearth. Two tuyeres (blow holes) situated in the furnace walls functioned to maintain a uniform blast of air. A door at the front of the furnace would have enabled tapping of molten copper and slag. Analysis of slag indicates that smelting was very effective, for the melting temperature was around 1200°C, the slag contains as little as 0.7% copper, and the crude metal contains more than 93% copper (Zhou Baoquan *et al.* 1988: 128-129).



(a)



(b)

Figure 9: (a) Remains of smelting furnace prior to the 5th c. B.C. with slag heap in background. (b) Reconstructed furnace (Huangshi Museum *et al.* 1980)

*Fuel*

Fuel required for the high-temperature smelting process is one that provides carbon. Charcoal is an obvious choice for it is easily available from timber; however, there is a limited natural supply of trees. Perhaps fuel was another limited natural resource that was in high demand in ancient China. Fuel was required at both mine and foundry sites for refining and casting. Hua Jueming (1988: 245) indicates that jet, which forms intergrowths with coal, was used for personal ornament in Neolithic and Bronze Age times. He states that the first archaeological evidence for the use of coal as fuel occurs at the Tieshengou site of iron and steel works in Gongxian, Henan. Although the coal is said to have been used for roasting, Hua does not provide a date for this roasting site. The type of fuel used in refining is not often mentioned in the papers I have consulted, perhaps because the fuel is indeed charcoal, as is widely assumed for this period, or perhaps because the assumption is not questioned.

# Chapter 5: Tin

Tin is the principal alloying agent in ancient Chinese bronze. Based on compositional studies of Shang and Zhou bronzes from the Sackler Collection, Meyers (1988: 292) concludes that tin was a deliberate addition. Tin functions to lower the melting point of copper and to increase the fluidity of the melt which eases casting. Also, tin concentration affects the color of the bronze; very high concentrations enhance reflective qualities of the bronze. Higher additions of tin also result in brittleness of the final product, which would not be desirable in weapons, but would not matter in the case of mirrors for which high reflectivity is achieved at the expense of a brittle product.

## Properties of tin

Tin occurs in only a limited number of forms in nature. Unlike copper, tin does not occur in the native state; the principle tin ore of major economic importance today is the oxide cassiterite ($SnO_2$). Cassiterite is a brown or black transparent mineral which is mainly found in secondary alluvial deposits (Barry and Thwaites 1983:22). Because of its resistance to weathering it survives for long periods in such an environment (Gettens 1969:8).

Tin occurs more rarely as a sulfide mineral; the principal sulfide ore of tin is stannite, a complex tin sulfide which is found associated with tin-bearing ore bodies. Stannite is very difficult to refine and contains only about 22% to 27% tin (Barry and Thwaites

1983:22). Stannite is supposedly the principal tin ore of the great Yunnan tin deposits (Gettens 1969: 8, 16). See Appendix 2 for a tabulation of the properties of tin and for comparison with copper and lead.

**Mining of tin**

Recent geological surveys indicate that tin ores exist in many areas of China, including central China. The largest tin belt in the world runs through southeast Asia into Yunnan in southwestern China. Another major tin deposit exists in Guangxi province, possibly an extension of the southeast Asian belt (Murowchick 1989: 64-65).

The origin of tin used in Shang and early Zhou bronze production, however, is not clear. Ancient tin mines have not been uncovered, which is not unusual considering that it is unlikely that tin was *mined* in ancient China. Muhly (1973: 248, Gettens 1969: 7) states that much of the economically important tin which is now mined in several parts of the world, including China and Indonesia, was not mined by the ancient metallurgist. The main source of ancient tin was stream tin, the secondary source of cassiterite nuggets deposited in alluvial environments. Tin could have been panned from a stream in the same way that gold was panned during the California gold rush.

According to Zhu Shoukang (1986: 8-9, after Wen Guang 1985), certain Shang and Zhou vessels bear accounts of tin deposits in central China. He states that geologists have confirmed that there were places to recover tin within the Yellow River valley. A vessel cast for the Marquis Yi of Zeng dating from the Spring and Autumn period supposedly bears an inscription stating that the Zeng state was a road for exchanging copper and tin. The Zeng state, located in Hubei province south of Suixian county, falls en route between the north and the south. The southern Chinese provinces of Yunnan, Guangxi, Hunan, and Guangdong bear rich tin deposits. Zhu states that, if pottery and jade were exchanged over long distances, there would be no problem in transporting tin from the south to the north during the Xia and Shang periods.

According to Gettens (1969: 17, after Li Chi 1957), Li Chi recorded two tin ingots found at Xiaotun, near Anyang, presumably of late Shang date, and stated that the form of the ingots suggests they were not locally produced.

The general lack of crude tin and tin artifacts in the archaeological record of ancient China may be due to the fact that tin metal is easily corroded when in contact with earth and thus tin objects would not easily survive (Gettens 1969: 8).

**Refining of tin**

There is no direct evidence of tin smelting from the Shang and Zhou periods. Gettens (1969: 8) points out that very little is known about the early metallurgy of tin, as copper metallurgy usually takes precedence in most studies. Tin may be extracted from cassiterite, or stream-tin, in a fairly simple procedure which does not necessitate the construction of a furnace. Gettens describes an example of tin smelting as presented in Aitchison (1960: 186). A deep trench or pit is filled with timber and is ignited. Crushed cassiterite and timber are then added alternately to the blaze and the molten tin flows to the bottom of the fire. In this method, tin yields are relatively low, as tin is lost in the slag and ashes at the bottom of the pit. Aitchison points out that this method of tin smelting is similar enough to lead smelting, which may also be accomplished in the hearth of an open fire, to encourage the idea that tin and lead were similar metals. Tin smelting yields may be increased if performed in a furnace similar to that used for copper smelting.

## Conclusions

Tin metallurgy is relatively simple compared with that of copper and lead. Since tin was not mined but was collected, it is difficult to say anything about control of natural resources. Provenance studies, which identify the primary source area of the metal, would not be useful in the case of tin for it was likely collected in a secondary deposit an unknown distance from its source. The simplicity of tin refining is significant in that it differs from the refining of oxide/carbonate copper ores, but is similar to the roasting step required in the refining sulfide copper ores. Thus the refining of tin may have stimulated copper refining technology.

# Chapter 6: Lead

Analysis of artifacts has shown that in most cases lead is the least abundant constituent of the ancient Chinese ternary alloy system. Like tin, lead was likely used to ease casting of copper by lowering the melting point and increasing fluidity. Addition of more than 4-5% lead, however, results in a soft bronze which is easier to finish and allows for more intricate design work (Linduff 1977: 15), but would not be suitable for implements requiring hardness and strength, such as tools and weapons (Gettens 1969: 42).

As with tin, we must first question whether it was initially an intentional addition, whether lead was mined and smelted in its own right, or whether it was accidently included as a byproduct from impurities in copper or tin. Compositional analysis of Shang and Zhou bronze vessels from the Sackler Gallery indicates that the vessels contain between 2% and 25% lead (I. L. Barnes *et al.* 1988: 298). Similar amounts of lead have been measured for the Freer Gallery bronzes as well (Gettens 1969: 42). Such a lead concentration is high enough to conclude that lead was indeed an intentional addition (I. L. Barnes *et al.* 1988: 298).

## Properties of lead

Unlike copper, lead does not occur as a native metal but is always found in combination with other elements in mineral form. The main lead ore in nature is galena, PbS, a simple sulfide mineral which occurs either in ore veins running through sedimentary and igneous rocks, or as crystals suspended in sedimentary deposits. Galena is easily recognized by its metallic gray luster and perfect cubic crystal form and often contains silver, arsenic, antimony, and other impurities. Near the surface galena may be altered to the oxide, carbonate, and sulfide minerals massicot ($PbO$), minium ($Pb_3O_4$), cerussite ($PbCO_3$), phosgenite ($Pb_2(CO_3)Cl_2$), anglesite ($PbSO_4$), and litharge; however, these secondary ores only contain from 1% to 20% lead (Nriagu 1983: 71, Pough 1983: 83). See Appendix 2 for a tabulation of the properties of lead and for comparison with the other metals.

Lead is toxic in mining, refining, and founding. The degree of lead poisoning, also known as plumbism, associated with mining depends on the ore type and on the miner's personal hygiene in terms of handling, inhaling, or ingesting the ore. Galena ($PbS$) is less toxic than oxide and carbonate lead ores and is not often associated with plumbism. This is due to its low solubility in the tissue fluids of the lungs and its coarser grain than the other lead ores. Recent plumbism epidemics are associated with carbonate lead ores (Nriagu 1983: 310-311). Lead refining is the highest risk task associated with lead mining and metallurgy due to inhalation of the fumes (p. 312). Lead poisoning may also occur from exposure to paints, glazes, and cosmetics which contain lead, from contamination of drinking water flowing through lead pipes, from the ingestion of lead elixirs (which are chronicled in ancient Chinese texts (p. 392)), and from contamination of beverages contained in lead-bearing vessels. Perhaps the correlation between degree of plumbism and ore-type can be used as a diagnostic tool in determining whether lead ore mined in ancient China was a sulfide (galena) or an oxide/carbonate ore. This is the subject of debate, the outcome of which will bear significance in other areas of ancient Chinese metallurgy, as discussed below.

Linduff (1977: 10) believes that plumbism may have occurred in ancient China from the drinking of wine out of bronze vessels. She attributes the sudden elimination of wine drinking vessels in the Western Zhou, as well as accounts of excessive drinking of the Shang kings, to plumbism. According to Chang (1994a: 33), alcoholic beverages played an important role in the ancient rituals. This is indicated in pre-Qin texts as well as in the oracle-bone record. Chang states that wine was offered to the ancestors and was used by those performing the ritual as well as by the shamans to induce a state of mind which induces communication with the ancestors. Since alcoholism and plumbism share similar characteristics, Linduff proposes that the downfall of the Shang may have resulted, in part, from lead poisoning. She suggests a study of bones from the Anyang tombs would reveal whether or not plumbism was a problem in Shang society (p. 15-16).

## Mining of lead

The archaeological record has yet to reveal ancient lead mines. Murowchick (1989: 58) suggests that the more recent mining of lead and silver, which often occur together, has obliterated traces of lead mining from the record. Therefore, information about mining of lead ores must be derived from secondary information such as chemical analysis of bronze artifacts (lead isotope studies), comparisons with the lead mining of other cultures (both ancient and modern) and with the copper mining techniques of ancient China, and from textual sources.

Lead was in good supply in early China and could be found in many provinces (Gettens 1969: 17, after Torgasheff 1930, Nriagu 1983: 174-175). Nriagu (1983: 174-176) states that there are rich lead deposits in Henan, Shansi, and Hebei, which are in close proximity to several of the Shang metallurgical centers. He also documents southern lead deposits. According to Linduff and Yan Ge (1990: 513), a provenance study using lead isotope analysis of Anyang bronzes has revealed that the source of the Anyang lead was in Yunnan province. This was reported at a conference in Kunming, Yunnan in October of 1988. I have not, however, seen these data mentioned in other studies.

A research team from the Smithsonian Institution has conducted lead isotope analysis of bronze artifacts from the Shang, Western Zhou, and Eastern Zhou periods and has found that many lead sources were exploited during Shang times, that fewer sources were used in the Western Zhou, and that by the Eastern Zhou lead was obtained from only a few locations (I. L. Barnes *et al.* 1988: 299). Reasons for this may only be speculated upon until more evidence and more scholarship is applied to the question of lead in ancient China.

Murowchick (1989: 58) states that ancient mining of lead and zinc in India, lead and silver mining in ancient Greece, and lead mining in Burma and Yunnan demonstrate that the mining of lead is very similar to the mining of copper. The Zawar lead/zinc mines of India use a similar water drainage system as that at Tonglüshan. The structure of the mines in Burma and Yunnan is similar to the ancient Chinese copper mines we have seen thus far (p. 59). Thus we may provisionally assume, unless new evidence suggesting otherwise comes to light, that lead mining knowledge was similar to that of copper.

**Refining of lead**

Lead smelting sites have likewise not survived in the archaeological record. Although chemical analyses of artifacts can reveal information about lead smelting, they may be interpreted in different ways.

According to Linduff (1977: 10), the earliest Chinese bronzes contain lead, and the amount of lead in bronze ritual vessels increases slowly throughout the Bronze Age. Gettens (1969: 42), however, states that according to data from the Freer Gallery bronzes, Zhou bronzes do not differ from Shang bronzes in lead composition. He states that in both periods lead addition was erratic.

Linduff (1977: 11, after Gettens 1969) uses Getten's analyses of bronze composition to conclude that a large amount of lead was regularly used in the Shang and Zhou alloys. Based on the existence of vessels cast almost entirely in lead (including one in the Freer Gallery, one in Holland, and six in the Hermitage Museum of Norfolk, Virginia (after White 1956: 176)), Linduff concludes that ancient metallurgists had the ability to extract and control lead no later than the Western Zhou (p. 12). Gettens (1969: 17-18), on the other hand, believes that lead metallurgy was independent from copper and tin metallurgy as early as the Shang period, a conclusion which he also bases on the existence of vessels cast entirely in lead. Gettens also suggests that lead metallurgy predated the metallurgy of tin and possibly even that of copper (p. 9). If this is true, then knowledge of lead sulfide metallurgy may have set the stage for understanding the need to roast copper sulfide ores.

Gettens (1969: 9) believes that the main lead ore used in the Chinese antiquity, as in the modern era, was galena, and that the extraction of lead from galena (PbS) was a fairly simple matter, even though it required removal of the sulfur, as in the case of copper sulfides. Since lead has a relatively low melting point of 327.4°C, the process merely involves the roasting of galena in contact with charcoal in the hearth of an open air fire. During roasting the sulfur is burned off as sulfur dioxide gas, and lead oxide reacts with lead sulfide and carbon to produce metallic lead. Because of its high specific gravity, the molten lead flows to the bottom of the hearth. Gettens suggests that perhaps the simplicity of lead extraction explains the scarcity of evidence in the archaeological record.

Linduff (1977: 13) believes that the main lead ore used in Chinese antiquity was not galena but a lead oxide or carbonate ore. Based on the fact that galena occurs in association with silver and the belief that the cupellation technique of separating lead and silver was unknown in China prior to the sixth century B.C., Linduff argues that, if galena was the main source of lead in ancient China, we should expect to see higher traces of silver in the bronze artifacts than analyses indicate. She observes that Shang bronzes tend to contain only small amounts of silver (less than 0.2%) prior to the 6th century B.C. Because of this and the fact that ancient Chinese smelting seems mostly applicable to oxide and carbonate ores, Linduff concludes that lead was smelted from oxide and carbonate ores such as cerussite ($PbCO_3$). However, cerussite is associated with only a slightly lower average concentration of silver than galena (Nriagu 1983: 70). Thus, like galena, the smelting of this carbonate ore would leave traces of silver in the refined metal.

After establishing that lead metallurgy was independent from copper and tin metallurgy as early as the Shang period on the basis of vessels cast entirely in lead, Gettens (1969: 9, 17-18) uses the low silver content of these lead vessels to support early knowledge of the cupellation technique for separating lead and silver, not to support the use of an ore associated with smaller quantities of silver as Linduff does. Gettens concludes that galena was likely smelted primarily to recover silver. He suggests that an investigation of the metallurgy of silver in early China would help resolve this issue (see next section).

**Silver and the cupellation process**

Like copper, silver occurs as a native metal, but apparently only rarely in ancient China (White and Bunker 1994: 34). Silver may be retrieved from mineral compounds by extraction of silver-bearing, or argentiferous, lead through the lead-smelting process, and then through cupellation. The cupellation process, in which lead is oxidized into slag and silver remains, consists of melting argentiferous lead in a furnace and subjecting it to a blast of air which causes the lead and other elements to be oxidized into slag, which may be skimmed off. The silver, which is not oxidized, remains in the metallic state, while the slag material may be resmelted to recover the lead (Nriagu 1983: 93). Some scholars believe that the cupellation process was realized as early as the Shang period (for example, Gettens 1969, and Zhu Shoukang and Zhang Boyin 1989), while others believe it was not known until a later date (for example, White and Bunker 1994, and Linduff 1977). Since such information bears directly on the lead component in the bronze metallurgy of ancient China, further investigation of this matter is important to the study of early Chinese bronze technology as well as to metallurgical knowledge in general.

According to Zhu Shoukang and Zhang Boyin (1989: edited author abstract from the Compendex CD-ROM index), silver was smelted no later than the Xia dynasty in ancient China. The nature of the evidence of Xia period silver smelting, however, is unclear from the brief author abstract. The authors state that they have visited ancient silver smelting sites in southwestern China.

Based on the rarity of native silver in early China, White and Bunker (1994: 34) believe that silver was likely imported or extracted from lead ores through the cupellation process. Based on artifactual and textual evidence, the authors conclude that silver was not an important metal in China until the Western Han period, since it is lacking from Bronze Age sites and does not seem to have been valued in Bronze Age China. The earliest silver artifact is from a

Neolithic Qijia culture site in Gansu province, dated 1600 B.C. by carbon-14; however, White and Bunker believe it is more likely of Central Asian than of Chinese origin (p. 51, no. 57). The authors state that silver has not been found in nuclear China before the middle of the Eastern Zhou. By the mid-Warring States, silver was used to inlay bronze items such as vessels, chariot fittings, and belt hooks. The earliest literary reference to silver is in the *Erya*, a dictionary of the third century B.C. (p. 34).

## Conclusions

Lead is the least abundant component of the ancient Chinese ternary alloy, and was an intentional addition. Interestingly, copper does not alloy well with lead (Gettens 1969: 7), although this did not deter ancient Chinese metal artisans from using it. Both tin and lead have low melting points (see Appendix 2) and may be smelted without a furnace. As Aitchison (1960: 186) points out, the smelting methods for tin and lead are similar enough to encourage the view that they are variants of the same type of metal. Also, several of the vessels from the Freer Gallery, the composition of which is presented in Table 1, do not contain lead. Perhaps tin was not always available or was a more precious resource and lead was seen as an acceptable substitute.

As in the case of tin, the simplicity of the lead refining process, which differs from that of copper but is similar to the roasting stage in sulfide copper ore refining, may have stimulated copper metallurgy, in terms of mining and smelting technology, as well as production level.

# Chapter 7: Conclusion

## Technological aspects of mining and smelting

Both mining and smelting technology exhibit progress during the Shang and Western Zhou periods. Mining technology progressed from open-pit mining during the Shang period to underground mining during the Western Zhou, as improvements in mining technology enabled deeper excavation of mines. Progress in smelting technology includes the ability to smelt sulfide ores, an accomplishment that was connected to the evolution of mining technology in that sulfides, the ores found at deeper levels of an ore body, require different methods of smelting than do the oxides, which are located near the surface. Since sulfide ores are located at deeper levels of the ore body, the ability to refine both oxide/carbonate and sulfide ores stimulated mining technology and also increased production levels. Thus not only is there a physical connection between mining and smelting, there is also a symbiotic relationship between them.

The ternary alloy of copper, tin, and lead, which is unique to China, was an important factor in the development of the magnificent bronze industry of the Shang and Western Zhou. Since all three constituents were deliberate and independent additions, and since all three have different properties, metallurgical knowledge was developed at a deeper level than with a binary alloy alone. The use of three separate metals stimulated the growth of the bronze industry, in terms of mining and smelting technology, production level, and perhaps even artistic ability, since combining three metals increases variability in the final properties of the bronze in terms of castibility, reflectivity, and color.

## Socio-political aspects of mining

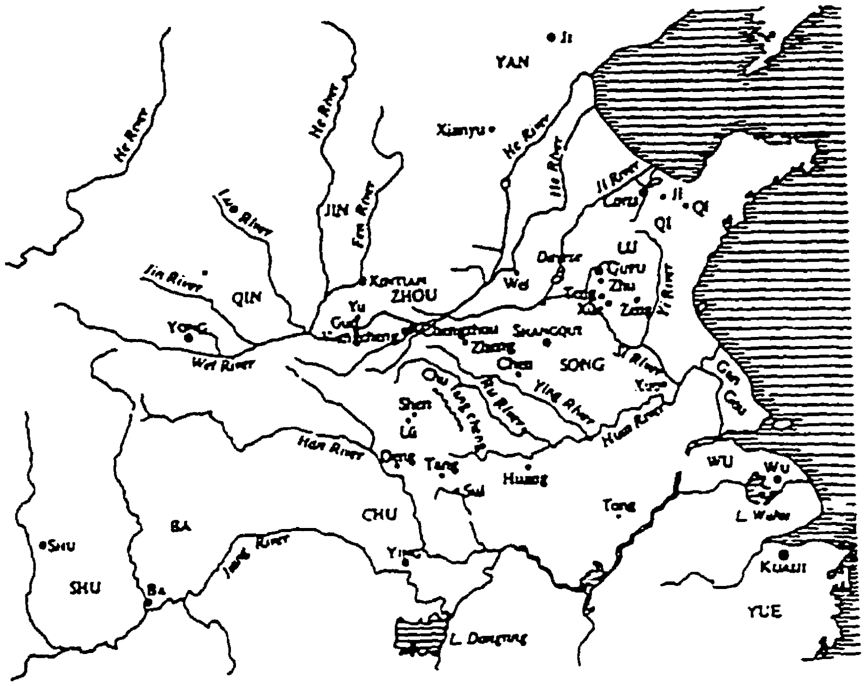
The wealth and political authority associated with bronze in ancient China indicates that the acquisition of metal ore would have been an important focus of the Shang and Zhou governments. It is clear that the state controlled the bronze foundries, and that the bronze founders, or at least their managers, enjoyed a higher status than that of the commoners. Did the state also control the fundamental resources necessary for the production of bronze? As previously mentioned, Chang (1983a: 104) speculates that the search for copper and tin and the protection of mines during the Three Dynasties would have required a considerable labor force to be mobilized by the government. Chang even proposes that movements of the capital were initiated in order to be closer to the mines.

### Zhou mining

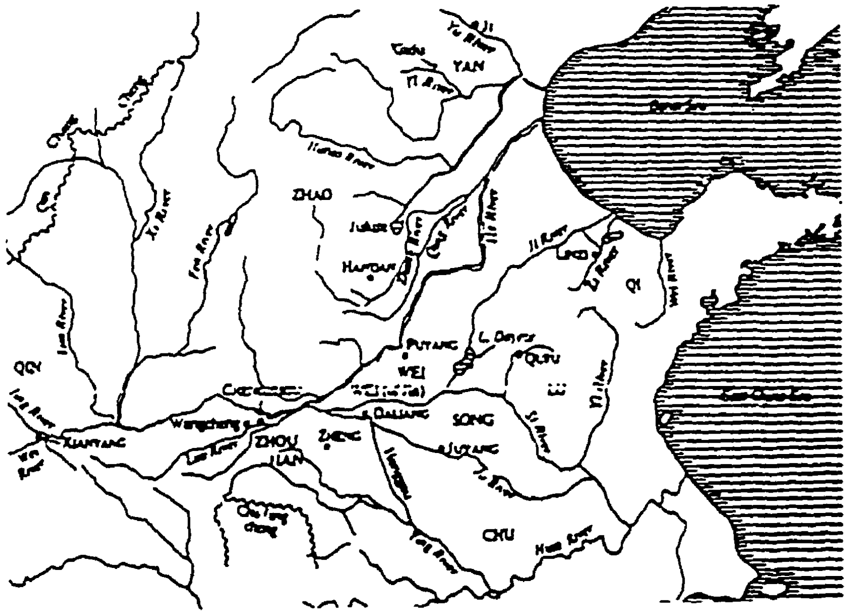
Evidence presented in this thesis leads me to conclude that the Zhou state did *not* control the major copper mines of its time. It is my hypothesis that the flourishing of the Chu state, a non-Zhou polity located on Zhou's southern border during the Eastern Zhou, was partly enabled by the existence of major copper resources within its territory.

The Tonglüshan, Gangxia, and Mayang copper mines are all located within the territory of the Eastern Zhou period Chu state. The Jinniudong copper mine is located in southern Anhui, perhaps within Chu borders or slightly to the east in an area thought to have been inhabited by the non-Zhou Wu people. The Chu polity was strong enough to resist subjugation by the Zhou and checked its southward expansion (Hsu and Linduff 1988: 225). Inscriptions from the Western Zhou period indicate that relations between the Zhou and the Chu were hostile at times (Cook 1990: 10). Three vessels from the time of the Zhou King Zhao (c. mid 10th century B.C.) contain inscriptions which indicate that the Zhou attacked the southern area to obtain metal, describing the outcome of the mission as "captured" or "gained" metal (p. 11, p. 32 no. 10). These vessels, the Guo Bo *gui*, the Fu Yu *gui*, and the Cai *gui*, are located in the Shanghai Museum.

According to Chang (1986a: 400-407), the rise of Chu civilization was prompted by Shang and Western Zhou influence which flowed south down the Han river and stimulated cultural growth of the indigenous Qinglongchuang III Neolithic culture. This is not necessarily the case. As in the case of the recently discovered highly developed sites in western Sichuan, which are thought to be independent from the Central Plains, the middle Yangtze River civilization also may have risen independently from that of the Central Plains. This does not preclude interaction between the two civilizations, but does question the one-way hierarchical relationship proposed by the classical view. Also, scholarship concerning the origins and pre-history of Chu before the Eastern Zhou period is in its initial stages and is now considered an important focus of Chinese archaeology (1986a :407).




(a)




(b)

Map 4: The Eastern Zhou state
a) Spring and Autumn period b) Warring States period
(Cook 1990:vii, viii; from Li Xueqin 1985: 6, 8)

The lack of evidence for large-scale mining activity within the Zhou borders, coupled with the flourishing and expansion of the Chu state during the Eastern Zhou, and evidence of Shang and Zhou sites in the area between the Central Plains and the middle Yangtze (showing potential contact between the two regions), strongly suggests that the Zhou were obtaining their raw copper from these southern mines. The economic, political, and social relationship between the Zhou and the Chu should be investigated from this angle. The flourishing and expansion of the Chu during the Eastern Zhou, while the southern mines were in operation, also suggests that the Chu may have been empowered by the control of these important resources.

Provenance studies, which attempt to determine the point of origin of the artifact's raw material, would be useful to test the hypothesis that the Zhou state did not control the major mines of its period. In this study, the chemical composition of both artifact and ore would be analyzed. If the chemical signature of copper ore from the southern mines matches that of the Zhou or Shang bronzes from the Central Plains area, we can say with more certainty that the Zhou and Shang were obtaining raw material from the South.

## Shang mining

As for the political situation of mining during the Shang period, the lack of evidence renders the situation more obscure. The only Shang period mine site I have been able to locate is the Linxi copper mine of Inner Mongolia, outside Shang and Zhou state borders. This area north of the Central Plains was home to hunting and herding cultures, such as the Zhukaigou site community of Inner Mongolia, and the Karasuk culture of Siberia. Although early Chinese texts refer to the northerners as hostile "barbarians" and erected the Great Wall against them in the late first millennium B.C., it is clear from the archaeological evidence that there was reciprocal cultural exchange between the Central Plains and the northern peoples of Inner Mongolia, Mongolia, and Siberia. According to So and Bunker (1995: 24), trade between these cultures generally involved manufactured goods from the Central Plains and raw materials from the north. The Shang and Zhou received horses, furs, carpets, jade, bone, and antler from the north, while the northerners received silk, cotton, bronze mirrors, metal belt ornaments, bridle fittings, and chariot ornaments from the Shang and Zhou. The authors do not, however, mention the possibility of trade of raw metals materials. Many mines have been located in the northern region, including the Linxi copper mine of Inner Mongolia. Ancient mines have also been discovered in in the Minusinsk basin of Siberia and in northern and northwestern Mongolia. Mines in the Mongolian Altai mountains were likely exploited beginning in the second millennium B.C., during the Shang and Western Zhou periods (Chernykh 1992).

The northern groups had a bronze metallurgy distinctive in technique, form, style, and alloy composition from that of the Central Plains, but we know that exchange of bronze weapons and decorative styles did occur. Commonly cited evidence of this exchange is the ring-pommeled knife distinctive of northern nomadic groups which appears at Shang sites and in royal Shang tombs, and the hybrid knife which combines both Central Plains and northern characteristics found in both northern and Shang and Zhou contexts. It is highly possible, therefore, that the Shang and Zhou were obtaining metal from the north. As I have suggested for the southern situation, provenance studies would be helpful in this case to determine whether or not the Shang and Zhou were obtaining raw metals materials from northern mines.

The Shang may also have been obtaining copper from the southern mines presented in this study. Although these mines began operation during the Zhou period, we must keep in mind the possibility that Shang period open-pit mining may be yet uncovered at these mines, or that it have been obliterated by subsequent ancient and modern underground mining activity or by erosion. Mining may very well have also occurred within the Shang boundaries; however, since physical evidence is lacking, this question needs to be addressed through other means, such as provenance studies or textual evidence.

An estimate of the amount of raw material necessary to produce the quantity of bronze artifacts yet unearthed from the Shang and Zhou periods would be useful. With such an estimate, we could determine whether large mines were exploited by the Shang and Zhou that have not been discovered, or whether they were indeed obtaining most of their ore from southern and northern locations. Chang (1983a: 103-104) has provided two examples of this type of calculation. In one case, the weight of the bronze artifacts from the Fu Hao Tomb was used to estimate how much raw material was used. An estimated 1,625 kg of bronze was unearthed from the tomb. Based on an estimated 1:5 ratio of raw ore to crude copper, approximately 8,000 kg of raw ore would have been used to manufacture the Fu Hao bronzes. A study in which similar calculations are made from dated and provenanced bronzes in museum collections and archaeological finds from the Zhou period, coupled with estimated yield from the mine sites, would help in determining whether the four Zhou period mines located in the Yangtze River valley would have been able to produce a sufficient quantity of crude copper to manufacture the Zhou bronzes.

Thus it appears that the Zhou and possibly the Shang were obtaining copper, the major constituent of bronze, from outside their borders. What trade relations were involved and to what degree the Central Plains cultures were obtaining raw material for bronze production await further study. Continuing study of Shang and Zhou period mining in China, along with further study of the Chu polity before and during the Eastern Zhou, will provide new evidence and new insights into the political and social aspects of mining in China during the Shang and Zhou periods.

## Rise of Chinese Civilizations

Evidence from this study suggests that the Three Dynasties of the Central Plains were not the only regions competing for wealth and power through bronze in ancient China. The Chu of the Middle Yangtze, and also the cultures of Sichuan as exemplified by the Longma and Sanxingdui sites, were also involved as separate entities, although they interacted with the Central Plains. A holistic view is necessary in which competition and interaction among all regions of ancient China are considered in what might be termed the "Bronze Age interaction sphere".

## Appendix 1: Glossary

The nomenclature related to mining and smelting can be slightly confusing because some of the terms are used loosely. This glossary contains a selection of the terminology related to mining and metallurgy which appears in this thesis.

**Alloy.** *n.* A mixture of two or more metals. The addition of secondary metals is usually to create new desired properties of the alloy which the main metal alone lacks. For example, the addition of tin, arsenic, or tin and lead to copper functions to lower the melting point and increase the fluidity of the melt, which eases casting. *v.* The process of melting two or more metals together.

**Anneal.** *v.* The process of heating metal in order to soften it. This smithying technique is often used in conjunction with hammering, which toughens the metal.

**Carbonates.** Carbonate minerals refer to compounds of elements with carbon and oxygen. Primary carbonate minerals form out of solution at depths in the earth or in the ocean. Secondary carbonate minerals form from the weathering of surface rocks with carbonic acid, which is produced by the combination of water with carbon dioxide from air (Pough 1983: 143-44).

**Crucible.** A vessel in which metals are melted and alloyed and from which they are poured into casting molds.

**Gangue.** Gangue refers to the minerals, or to any portion of the ore body, that are of no economic value. "Gangue" is sometimes loosely interchanged with the term "slag", which is the waste product of smelting.

**Grade.** The ore-grade refers to the quality of the ore in terms of concentration of the desired element. High grade copper ores contain a high concentration of copper, whereas low grade copper ore contains a low concentration of the desired element and a high concentration of gangue.

**Native.** A native element occurs in an uncombined, pure state. Certain metals, semi-metals, and non-metals occur in the native state. For metals this includes copper, silver, gold, iron, mercury and platinum. For the semi-metals, this includes arsenic and tellurium. For the non-metals, this includes sulfur and carbon (as diamond and graphite) (Pough 1983: 71-79).

**Ore.** A mineral containing the desired element to be mined, such as copper, and occurring in sufficient quantity to make its extraction profitable (e.g. "copper ore") (Pough 1983: 299). The term "ore" is also applied more loosely to the body of rock which contains ore minerals as well as gangue.

**Mineral.** Solid mixtures of one or more the 92 relatively stable elements (listed in the Periodic Table of the elements) from the

Earth's crust discovered thus far (Pough 1983: 12).

**Oxides.** Oxide minerals refer to compounds of metallic elements with oxygen. Most oxides are formed close to the surface from the weathering of other minerals (Pough 1983: 189-109).

**Specific gravity.** A system of weight measurement used for minerals. The specific gravity of a substance is the weight of the substance in relation to the weight of the same volume of water. For example, a substance with a specific gravity of 6 would be 6 times as heavy as the same volume of water (Pough 1983: 30).

**Sulfides.** Sulfide minerals refer to compounds of metallic elements and sub-metallic elements with sulfur. Sulfide ores are easily recognizable by their metallic luster and their brittleness distinguishes them from native metals. Close to the surface, sulfides are altered to oxides and carbonates by groundwater circulation; thus, sulfides are usually encountered at deeper levels in mines (Pough 1983: 79-80). This may be seen in Figure 8, a diagram of the Tonglüshan ore body.

## Appendix 2: Physical properties of the metals

| | Copper (Cu) | Tin (Sn) | Lead (Pb) |
|---|---|---|---|
| Melting point | 1083°C | 231.9°C | 324°C |
| Specific gravity | 8.9 | 7.3 | 11.35 |
| Principal ores | Native copper<br>Cuprite ($Cu_2O$)<br>Tenorite (CuO)<br>Malachite<br>($Cu_2(OH)_2CO_3$)<br>Azurite<br>($Cu_3(OH)_2(CO_3)_2$<br>Chalcopyrite ($CuFeS_2$)<br>Bornite ($Cu_5FeS_4$) | Cassiterite<br>($SnO_2$)<br><br>(Stannite,<br>complex<br>sulfide) | Galena<br>(PbS) |

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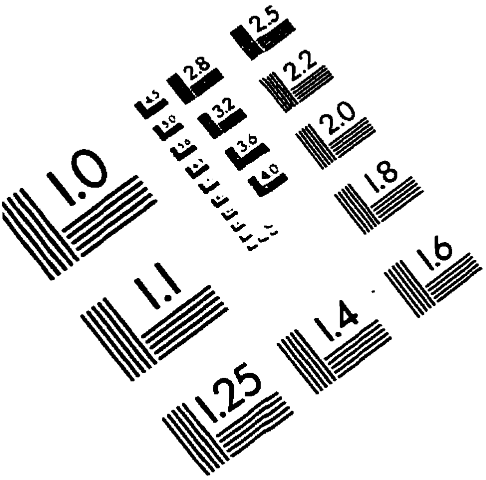

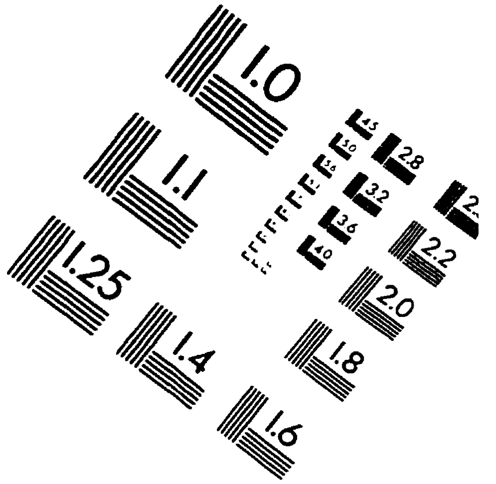

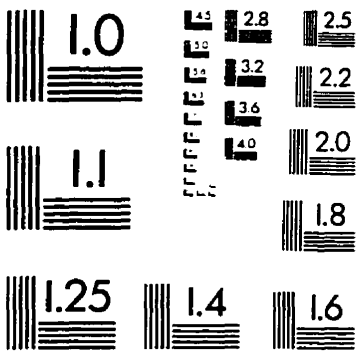

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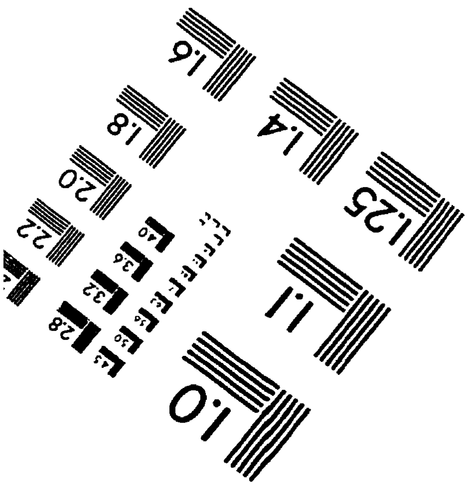

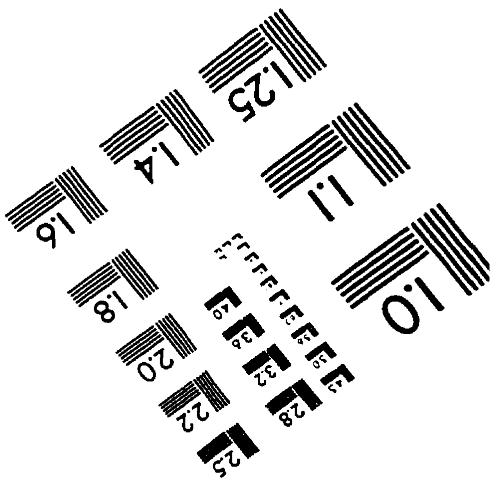

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