

# Unearthing Technology's Influence on the Ancient Chinese Dynasties through Metallurgical Investigations



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It was believed that Chinese civilization developed in the Central Plains area of the Yellow River. In the last 50 years, however, major excavation have been undertaken in Sichuan, Shaanxi, Shanxi, Hebei, Shandong, Henan, Chongqing and Hubei, areas thought to be primitive and devoid of historical context. Our understanding of Chinese history and its contributions to the Bronze Age was fundamentally changed with recent discoveries. In China, the Bronze Age was assumed to have started around 1900 BC, although the earliest dated bronze objects in China are from approximately 3000 BC, similar to the time Greece began using bronze. For comparison, the pre-Columbian civilizations of the Americas had bronze technology in 1000 AD. The high temperatures of the Neolithic kilns used to fire pottery were hot enough to melt metals from stone; pottery kilns found near Xi'an could maintain temperatures at 1400 °C as early as 5000 BC. Casting was a more natural progression for the Chinese who had a long history with pottery and jade carving since the Neolithic period. The Europeans were far more reliant on hammering and working the metal into shape during their Bronze Age. For this reason, scholars believe Chinese artisans were able to develop bronze without the influence of other cultures, suggesting an independent Chinese discovery of bronze.

Bronzes from ancient civilizations provide insight into the cultures of 4000 years ago. There is great appreciation for the progression of metallurgical processing techniques that evolved over thousands of years. The materials and metallurgical techniques can be studied to provide information about material structure and the technology used to manufacture the objects. Investigations of structure and chemistry are useful for documentation as well as for preservation and restoration, establishing better estimates about timelines, place of origin and probable use. Several of the artifacts in the Tseng collection were examined in the Advanced Materials Laboratory at California State University Northridge (College of Engineering). Most of the samples were too large to directly place in the chamber of a Scanning Electron Microscope, so analysis was done on surface deposits removed with carbon tape. The Chinese objects included a bronze vessel with jade dragon handles and a copper/gold lid, a bronze guang with animal characteristics, and a bronze ding. For each sample, micrographs were taken, spectrum analyses were obtained and elemental compositions were calculated. Actual bronze alloy percentages vary significantly in the amounts of copper (90% - 50%), tin (10% - 50%), lead, silver and iron used for ancient bronzes. Many of the artifacts demonstrate thin walled casting and unique surface decoration. The ancient Chinese developed a most unusual casting method called the piece mold process where surface decoration could be made by carving into the mold or into the model. The Tseng collection provides possibility for metallurgical examination and collaboration with archaeologists and conservators from other institutions on a cultural and scientific level, giving an unprecedented opportunity to explore the art, material culture and spiritual life of ancient China.

## **Approximate Timeline**

### **Neolithic Period (8000-1700) BC**

- Yangshao culture (5000-3000) BC
- Hongshan culture (4700-2500) BC
- Dawenkou culture (4300-2500) BC
- Majiayao culture (3100-2700) BC
- Liangzhu culture (3300-2200) BC
- Longshan (2600-2000) BC

### **Xia (2100-1600) BC**

- Erlitou culture (1900-1600) BC

### **Ba (2000-220) BC**

### **Bronze Age (1766-121) BC**

### **Shang (1700-1100) BC**

- Zhengzhou phase (1600-1400) BC
- Erligang culture (1500-1300) BC
- Anyang phase (1300-1100) BC
- Yinxu culture (1200-1050) BC

### **Zhou (1100-256) BC**

- Western Zhou (1100-771) BC
- Eastern Zhou (770-256) BC
- Spring and Autumn period (770-476) BC

### **Warring States (475-221) BC**

### **Qin (221-206) BC**

## Chinese Civilization

Despite centuries of migration and intermingling with other cultures the Chinese possess a distinctive system of writing, philosophy and art. It is, perhaps, their reverence for history and ancestry that has provided an underlying continuity for thousands of years. China is characterized by dramatic geographic and cultural diversity that has impacted the development and expansion of the Chinese civilization [1]. Chinese ancestry dates back to approximately 8000 BC with the Neolithic cultures [2], the Yangshao and Hongshan cultures arrived around 4000 BC [2], and several dynasties (Xia, Shang, Zhou, Qin) coexisted during the Bronze Age. Prior to the discoveries made in the late 20<sup>th</sup> century, Chinese civilization was thought to have developed in the Central Plains (**Zhongyuan**) area of the Yellow River (**Huang He**) [2]. The Yellow River Valley was heavily excavated in the 1950s to prepare for national infrastructure construction projects and the Sanmenxia Yellow River Reservoir. It was in this area that ancient sites of the **Yangshao** were unearthed. Major areas of excavation have been undertaken in Sichuan, Shaanxi, Shanxi, Hebei, Shandong, Henan, Chongqing and Hubei (Figure 1). In the Republic of China today, the beauty of traditional bronze art is still apparent with incense burners and in sacrificial vessels found in the temples and statues; all have been influenced by the ancient Chinese bronzes. The traditional bronze design is still a central theme to modern architecture and even furniture design [3, 4].



Figure 1 - Map showing many of the Chinese provinces where the ancient cultures lived [5].

Many Chinese live in the largest province of **Sichuan** (Szechwan), situated in southern China (Figure 2). Today, industries in the Sichuan province include iron and copper smelting, machinery, power, coal mining, petroleum refining, chemicals, textiles, and food processing. **Sichuan** is also known for its hand weaving of cloth, production of silk products, silver smiths, copper smiths and embroidery [6]. The site of **Sanxingdui**, located in the city of **Guangan** is recognized as one of the most important ancient remains in the world for its vast size, lengthy period and enriched cultural contents.

**Chongqing**, situated on a rocky peninsula at the confluence of the Yangtze, Yichang and Jialing rivers, is an autonomous municipality that shares borders with **Sichuan, Hubei and Shaanxi**. It serves as a major inland port for China. The city is located near iron ore and coal deposits in a fertile agricultural region. Manufacturing exploits include metallurgical industries that produce quality steels and aluminum, machinery, motor vehicles, cotton and silk textiles, chemicals, pharmaceuticals and processed foods. Major railroads and highways link Chongqing to all parts of the country [6, 7]. A city has existed here for more than 4000 years. In the 4th century BC it was absorbed by the Qin dynasty becoming the first unified Chinese state [7].



Figure 2 - Map of Sichuan province [8].

**Hubei**, in central China, extends across two major river systems, the **Yangtze** and **Hanjiang** [9]. The western Hubei mountainous area includes the Wudang, Jingshan, Daba and Wushan Mountains. Hubei has more than 1,000 rivers, more than any other province in China. The Yangtze River has strongly influenced the lives and culture of those living along it. Running roughly 3937 miles from the Tibetan Plateau to its mouth near Shanghai, the world's third largest river has figured heavily into agricultural and transportation activity, as well as having spiritual significance. Although the Yangtze has flooded countless times throughout history, by far the most catastrophic of these floods occurred in August of 1975, when an unusual weather pattern caused the Banqiao and Shimantan dams to collapse, releasing a combined 720 million cubic meters of water, killing 85,000 and leaving many more homeless. The construction of a dam at Three Gorges was officially launched in 1994 [10]. The **Three Gorges Dam** spans the Yangtze



River at Sandouping, Yichang, Hubei province (Figure 3). It will be the largest hydroelectric dam in the world when completed in 2009.

**Shaanxi** is an inland province along the middle reaches of the Yellow River. The Eurasia Continental Bridge, an international economic link starting from Lianyungang in the east and ending in Rotterdam, Netherlands, traverses through the province. It borders Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region and the provinces of Shanxi, Henan, Hubei, Sichuan and Gansu [9].

**Henan** Province is located in eastern central China on the plains between the Yellow and Huaihe rivers. Because Henan was called Yuzhou and considered the center of China more than 2,000 years ago, the province is called Yu for short, and also referred to as Zhongzhou (Central Prefecture) and Zhongyuan (Central Plain). Neighboring provinces are Hebei, Shanxi, Shaanxi, Hubei, Anhui and Shandong [9]. One of the earliest developed regions in the country, Henan was a political and cultural center in ancient China. In the remote past, China was divided into nine geographical regions, and Henan was called the "Central Region" or "Central Plain" because it was situated in the middle of the nine regions. Henan is one of the most densely populated provinces [11].



Figure 3 – Map showing Yangtze River in Chongqing province [12]. The controversial Three Gorges Dam along this river is planned to be the largest hydroelectric dam in the world [13].

### Archaeology

Archaeological evidence is important for our understanding of history. For periods before writing, surviving artifacts offer a source of corroboration to legend and myth. The Chinese have records dating back 3,300 years. However, Chinese history, until the twentieth century, was written predominantly by members of the ruling scholars or official class and was intended to provide guidance or mandates for future rulers. These accounts focused on politics and colorful court histories with superficial mention of commoners [14]. Even after writing was invented, texts that survived were very limited, so there is still a great deal to learn from artifacts. Scientifically excavated objects can be placed more accurately in time and place than early texts that were often revised and edited throughout history. Thousands of early archaeological sites have been excavated in China, most of them graves of the wealthy ruling class [1]. By the late 1920's,

archaeologists were systematically excavating burial sites. Today, many scientific dating methods are available including radiocarbon dating for organic material and thermoluminescence (TL) dating that can measure the amount of natural radiation an object has been exposed to over the course of its life [2].

**Archaeological Stratigraphy** is based on the concept that different cultural layers or sites are gradually built on top of a preceding layer over a period of time [15]. The law of superposition states that the earliest strata are usually the deepest; some exceptions occur in disturbed strata with riverbank flood deposits or the construction of mounds [16]. The large scale archaeological excavations conducted at the ruins of Yin in Anyang, Henan province in 1926 are a well known example of the application of archaeological stratigraphy in an excavation. Having surveyed the sequence of layers, it was discovered that Tomb 1550 was located on the layer above the southern ramp of Tomb 1001; from this it was assumed that Tomb 1001 must have preceded Tomb 1550 [15]. **Cultural Layer** refers to the traces of human habitation and objects of everyday use left behind in a given area. Over time these deposits build up on top of each other and, precluding major earth movements or human interference, it is assumed that lower layers are older than those above. Archaeologists are then able to make assumptions about the sequence of different cultures in a given area from the order of these cultural layers.

**Remote sensing** usually involves a technical device that helps to determine what is under the ground without having to physically be there. Remote sensing can include sophisticated aerial photos, mapping, infrared photography, satellite images, pictures generated by various geophysical prospecting techniques like magnetometers, electrical resistivity detectors, ground penetrating radar (GPR), sonar and other military imaging technology. Buried or heavy jungle areas can hide ancient canals, buildings, mounds and treasures. With remote sensing, site discovery is greatly enhanced [16]. Global Positioning Satellites (GPS) can give exact locations of buried sites and Geographic Information Systems (GIS) can provide computerized maps emphasizing different features that can be overlaid to show relationships of natural and cultural features through time. Site survey and mapping can be done at several levels, from a rough sketch using a compass and pacing distances, to formal mapping with a surveyor's transit and electronic station [16]. One of the first applications of time slice analysis of **ground penetrating radar** (GPR) in **archaeological prospection** was reported in 1990 [17] and several more advanced methods for creating topographically corrected time slices and general horizon slicing were presented [18] in 1994. The advancement of static corrections in the geophysical processing of raw radar records has significantly improved the quality and utility of ground penetrating radar datasets collected at archaeological sites with topographic relief. Horizon slicing, the most general form of slicing a user defined surface through a 3-D dataset, is used to image structures below subsurface interfaces that have unequal overburden thicknesses [19]. One example of a horizon slice applied in the search of a Jomon Period (1000 BC) habitation site in Guma prefecture, Japan was recently analyzed (Goodman, 1995). The results of horizon slices made below a pumice and ash layer that buried the site, are used to find traces of ancient dwelling foundations [20].



In the field of archaeology, **seriation** is a method of dating objects. Before scientific methods like carbon dating were introduced, dating archaeological finds and features was a difficult task. Typological sequencing was developed in the nineteenth century to create relative chronologies for prehistoric European tools. The sequencing method that assumed that changes in artifact design were incremental, that different cultures would produce different designs and that neighboring cultures would influence one another led to a model for relative chronological sequencing. Once a definitive date has been ascribed to one or two artifacts that have been arranged in chronological order through historical or archaeological evidence, these period markers can be used, in conjunction with other artifacts from a similar period, to determine morphology, style, decoration, and ascertain a relative age for other objects; essentially these period markers are used as a comparison to evaluate characteristics [15]. This method is still widely used, though it requires a wide range of design types in large quantities to work well [21]. To authenticate a bronze, casting technique, degree of oxidation, shape, inscription and decoration are examined. The amount of oxidation surrounding the characters is also important. **Radiometric dating** is a technique used to date materials based on knowledge of the decay rates of naturally occurring isotopes, and their current abundances; various methods (differing in accuracy, cost and applicable time scale) exist. **Radiocarbon dating** is the use of the naturally occurring isotope carbon-14 in radiometric dating to determine the age of organic materials, up to 50,000 years [22].

### **Artifact authentication**

In 1979, a Chinese **fang lei vessel** was sent for examination to the Metropolitan Museum of Art Laboratory. It was a ritual bronze from the Shang Dynasty, dating from around 1200 BC. Thanks to a huge undertaking on the part of the Chinese government to support new archaeological projects, many recently excavated bronzes had been sent to New York, so this was a routine test. By examining a tiny **metallographic** sample of the vessel under a microscope, the conservators were able to detect the presence of **intergranular corrosion**, confirming that the object had been buried for centuries. However, the vessel was also x-rayed, revealing a precise saw cut on the radiograph. Someone, recently, had cut the vessel in half and soldered it to another metal object. As it turned out, the bottom half of the vessel had been cast after excavation. Several months later, a nearly identical vessel turned up in a private collection. It seemed that soon after the excavation, a mold was made of the original vessel, then the original was sawed in half and remade into two partially “authentic” vessels. More recently, another vessel turned out to be a composite of twelve different ding vessels. Not really surprising since there are many of these ding vessels accessible; most however, are “technically crude and stylistically unconvincing pieces” [23]; often the wrong technique is used (lost wax instead of piece mold). Some pieces appear stylistically genuine (Figure 4), but when analyzed in the lab, the metal reveals technical inconsistencies. The Chinese government not only condones the creation of exact copies of archaeological finds, they finance it; “conserving by copying” is taken for granted. It was discovered that the majority of the Qin Shihuangdi terra cotta warriors seen in American museums in the 1980s were copies [24].



Figure 4 - Antique market where copies and “authentic” objects can be purchased.

### Important archaeological discoveries

Archaeological work uncovered eleven major Shang royal tombs and the foundations of palace and ritual sites. Thousands of bronze, jade, stone, bone (more than 20,000 inscribed oracle bones were discovered) and ceramic artifacts of high quality workmanship have been obtained. Many Chinese characters found in the inscriptions at the Ruins of Yin are still in use today. An ancient tomb dating back to over 3,000 years ago was excavated in 2005 at the famous **Yin Ruins** in central China. Coffins painted in red and carved with dragon patterns were found in the tomb together with more than 570 bronzes, jades and other funeral objects. New discoveries also include a bronze instrument and a shield that had not been seen before in the Yin Ruins. From the inscriptions on the excavated bronzes and the large quantity of weapons unearthed, archaeologists concluded that the occupant of the tomb was a high ranking military officer for an emperor of the Shang Dynasty. Covering an area of 24 square kilometers, the Yin Ruins in **Anyang** County, Henan Province, were the site of the Shang Dynasty Capital for 273 years. To the northwest of the newly found tombs lies the tomb of **Fu Hao** [25]. In 1928, excavations begun in Anyang (Figure 5), revealed a large number of artifacts and valuable remains, including palace ruins, a royal cemetery, tombs, workshops, tools, musical instruments and bronze vessels. Also a great number of burial pits were unearthed here in 1976, including the famous tomb of Fu Hao, female general and consort of the powerful king Wu Ding who died around 1200 BC. It contained two hundred ceremonial bronze vessels, most bearing inscriptions to the memory of Fu Hao. This discovery was a milestone in the understanding of the lives of Shang kings and aristocracy [26].



Figure 5 – Excavation of the Fu Hao tomb [15].

Altogether the bronzes found in Fu Hao's tomb weighed 1.6 metric tons (Figure 6), a sign of the enormous wealth of the royal family. These vessels were not only valuable by virtue of their material, a strong alloy of copper, tin and lead, but also because of the difficult process of creating them. The **piece mold technique**, used exclusively in China, required a great deal of time and skill [27]. From 1955 onward, hoards of bronze ware (from Western Zhou Dynasty) have been discovered in **Shaanxi province**, mostly consisting of vessels buried there by the royal families as they fled from intruding northern barbarians during the last years of the Dynasty [26].

The first **Sanxingdui** relics were discovered by a farmer in 1929 [28]. Since this time, generations of archaeologists have worked the digs and studied the **Sanxingdui** culture. In 1986, Chinese archaeologists discovered two major sacrificial pits containing nearly **1000** bronze objects (hundreds of masks and heads, artworks in jade, gold and stone; no texts were found). Analysis of lead and other elements in the bronzes indicates sources similar to those of other cultures along the lower reaches of the **Yangtze River** [26, 28]. The scientific discoveries and excavations at Sanxingdui have revealed historical evidence of the **Ancient Shu** from a period 5,000 years ago; **Shu was the ancient name for Sichuan**.

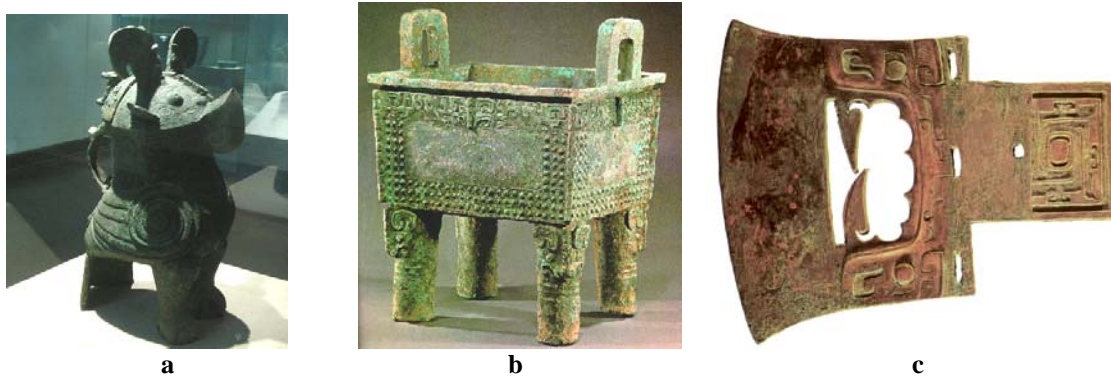


Figure 6 – a) owl shaped zun (bronze wine vessel) from Fu Hao tomb on display at the National Museum of Chinese History in Beijing, China; late Shang period [29]; b) Bronze ding vessel; Height: 80.1cm, Weight: 128kg; c) Bronze ax from Fu Hao tomb [27];

The Sanxingdui remains are composed of several large relic areas that cover 12 square km in total [28]. **Site No. 1** contents: (discovered on 18th July 1986) - ten jade dagger-axes and jade tablets; bronze dagger-axes with features of the early Shang; bronze image with long hair, a helmet and facemask. Among the bronze vessels, there are images, bending figures, dragon stick vessels, dragon ornaments, tiger ornaments, plates, covers, dagger-axes. The jade ware includes: jade tables, dagger-axes, swords; pottery includes: pointed base cups, flat basins and utensils bases. There are also a great number of clamshells, ivory pieces and pieces of burned bone [28]. **Site No. 2** contents: (discovered on 14th August 1986) - roughly 25 meters from Site No. 1. The objects in No. 2 pit totaled over 800 pieces (Figure 7). Sculptures with animal and human faces, bronze wares, plant ashes, charcoal powder, small bronze wares, masks (Figure 17), drinking vessels, bronze trees, dagger-axes, sun shaped wares, bells, decorative dragons, snakes and birds. There were also gold tables, gold masks and gold belts (Figure 19). The jade

ware included dagger-axes, tablets, rings, knives, beads, tubes. There were 60 ivory objects (elephant tusks) and many clamshells [28].



Figure 7 – (left to right) bronze artifacts recovered from the Sanxingdui excavation in Sichuan Province, now at the Sanxingdui Museum in Guanghan [2]. Catalogue No. 17, bronze head, late Shang, ~ 1200 BC, H: 13.6 cm, width: 10.8 cm, weight: 0.71 kg; Catalogue No. 5, bronze head, middle Shang, ~1250 BC, H: 25 cm, width: 20.4 cm, weight: 3.36 kg; Catalogue No. 33, bronze bird head, late Shang, ~ 1200 BC, Length from side to side: 38.8 cm; H: 40.3 cm; Catalogue No. 4, bronze head, middle Shang, ~1250 BC, H: 29 cm, width: 20.6 cm, weight: 4.48 kg; Catalogue No. 7, bronze head, middle Shang, ~1250 BC, H: 27 cm, width: 22.8 cm, weight: 7.66 kg [30].

In 1972, a large quantity of **Ba kingdom bronzes** was found in the village of **Xiaotianxi** in Chongqing. For more than 2,000 years, the Ba people made significant contributions to the development of a vast region covering Hubei, Chongqing, Jiangxi, Sichuan and Hunan provinces [31]. Before the Han Empire in 200 BC, the people of the Sichuan basin did not leave a record of themselves [5]. Information about the Ba and Shu people comes from Shang and Zhou dynasty historical documents. There is reference to the Ba and Shu in oracle texts from over 2000 years ago at the Anyang site; it is not clear whether Ba and Shu were cultures, states, or ethnic minorities. Furthermore, these people were not believed to have come from Sichuan [5]. According to legends and myths, at its height, the Ba kingdom was more powerful than the Zhou, and then suddenly declined during the Warring States. Between 1972 and 1993, four salvage excavations were conducted on the Xiaotianxi Ruins (Figure 8) and cultural relics from nine of the tombs were collected and studied [31]. Despite the great progress that has been made in archaeological research of the Ba people, it still has not been determined whether the Ba people were natives of the Three Gorges. In 1989, about 10,000 Ba relics were unearthed in an area of 400 square meters in **Xianglushi**, not far from the Wuluo Zhongli Mountains. Though the Ba Kingdom was later conquered by the Qin, its culture did not disappear immediately; Ba style pots were found in Han tombs [31]. In 1994, an exploration team found burial grounds for ancient Ba aristocrats. Additional Ba tombs were discovered at the **Lijiaba Ruins in Yunyang**, these however appeared to be tombs of common Ba people. A large amount of bronzes and jade wares typical of Ba culture were unearthed [31]. Little is known about the Ba, however, distinctive boat-shaped coffins, elaborate weaponry and bronze work have been found in the ruins [32]. The **Shuangyantang** site, the largest (100,000 sq meter) residential area of the Ba people (from 1000 - 771 BC) was dug up in 1994 to make way for the dam. Found among the ruins were shards of pottery, stone musical instruments, jade pendants, bronze fish hooks and cooking stoves. The luxury items suggest that the Shuangyantang site may have been the capital city of the ancient state of Ba [33].



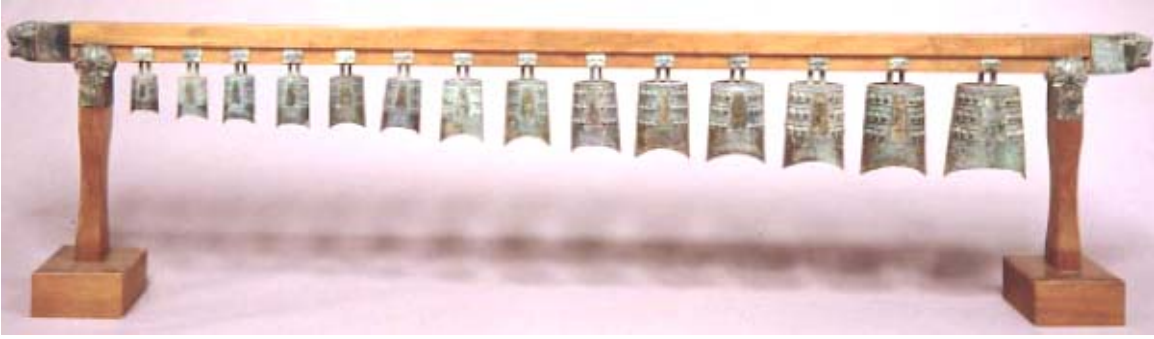


Figure 8 – **Chime of fourteen niuzhong**, bronze with gold inlay; bells range in height from 27.5 cm to 14.6 cm; c. 300 BC, excavated in 1972 from tomb 1 at Fuling Xiaotianxi, Sichuan Province [30].

**Jinsha Ruins** were accidentally discovered on February 8, 2001 when builders from a local real estate development firm were working at a construction site in Jinsha Village. They found ivory and jade embedded in the mud. Since then, archaeologists have excavated more than 1,000 precious relics of gold, jade, bronze, stone and nearly 1 ton of ivory. Most of the pieces are 3,000 years old. Many of the relics (including a gold mask and a bronze statue) bear strong resemblance to those at Sanxingdui. The decorative patterns on the gold ribbon unearthed at Jinsha are also similar to those on the gold scepter at Sanxingdui, the symbol of royal power of the **Shu king**. The Jinsha Ruins have extended Chengdu's history by about 700 years and strengthened the theory that Chinese civilization had many origins and diverse roots. The excavations (Figure 9) prove that rulers of the ancient Shu Kingdom established its political and cultural center in **Chengdu** more than 3,000 years ago [34, 35].



Figure 9 - Excavation site at Jinsha (left) and exposed ivory tusks, bones and other remnants [34].

### **Ancient Cultures of the Erlitou, Erligang and Shang**

During the Neolithic period, each region in China had its own local style of burial pottery and jade. The first known bronze vessels were found at **Erlitou** near the Yellow River in northern central China. Most archaeologists now identify this site with the **Xia dynasty** mentioned in ancient texts as the first of the three ancient dynasties (Xia, Shang and Zhou) [36]. **Erlitou culture** was the first to introduce industrial casting of bronze vessels and weapons using **the piece mold method** [37]. Erlitou culture sites are distributed over Shanxi and Henan Province [38]. The styles of the bronzes dating to 1600 - 1400 BC are

remarkably similar, but significant changes are apparent from 1400-1300 BC. Crude, thin and simply decorated bronze vessels of the **Erlitou** Culture (Figure 10) type have been excavated from the Yellow River valley over the years at the site of Erlitou, Yen-shih in Hunan. Early Shang bronzes are represented by the **Erligang phase** vessels excavated from **Erligang** at Cheng-chou, Hunan. [15]. Archeological findings show evidence that the core of the **Shang's** homeland in Anyang was only part of a multi-centered world, each with different cultures and styles of art and living [28]. The Shang (Yin) Dynasty traces its roots south of the Yellow River in Erlitou near **Luoyang**. The Shang society was already divided into slave labor groups of former war prisoners. The people living far from the capital were barbarians and enemies. The stratified society needed laborers and most were conscripts and slaves [27, 37]. **Archaeological evidence** about the Shang comes mainly from the excavations at Zhengzhou and Anyang.



Figure 10 – **a)** Erligang **jia** from Zengzhou; **b)** Ding with net pattern from Erlitou period (height: 20 cm) [15]; **c)** Ding from Shang/Zhou period, sold for \$1.5 million at Christie's auction [39].

## Weapons

It was during the Shang, however, that bronze casting was vastly improved [15]. Bronze artifacts evolved to their heights of artistic elaboration in form, decoration, inscription, as well as in the technological aspects. The most common Shang bronzes were the ritual objects, food containers and wine vessels, however, **weapons** and **musical instruments** have been found. Many ritual bronzes were engraved with records of military exploits, extremely valuable for historical research [40]. The Shang dynasty was a period of great beginnings in Chinese civilization. Towns, collective agriculture and organized military activity appeared for the first time. The Chinese written language emerged among the Shang people and provides an important historical context to the many artifacts unearthed from Shang tombs and other archaeological sites. As is true of other cultures around the world, bronze was first exploited for making weapons. **Bronze spears, swords, daggers and halberds** (Figure 11) gave the Shang superiority over neighboring kingdoms. Not surprisingly, the mining of metals and the casting of molten bronze were industries tightly controlled by the Shang rulers [36]. Large **yue axes** were probably used for ritual sacrifices. During Shang times, human sacrifices to the ancestors accompanied cult ceremonies, the construction of buildings, and the burials of the elite society. Many of these sacrificed people were probably prisoners of war from the Shang's frequent battles against its neighbors.





Figure 11 – **a**) Yue, an ancient axe used by military commanders and in ritual ceremonies, (Shang Dynasty) [3] **b**) Dagger axe (Ge) with pig and whorls, Anyang phase 1300-1050 BC, cast bronze, photographed at LACMA; **c**) Bronze, turquoise, and jade dagger (halberd), Anyang ~1100 BC, H: 34.8 cm, W: 17.6 cm, D: 5.4 cm [43].

### Musical instruments

Chime bells were of great political significance and were material affirmations of the Chinese technical skills. **Nao** bells are the earliest chime bells from any culture in the ancient world. Although similar in shape to northern nao bells, southern nao are much larger, heavier, more elaborately decorated, and may have served a very different ritual function. Rather than serving as a musical instrument in an orchestra, the southern nao is more similar in function to Buddhist temple bells or to later European church bells [41]. Bronze bells were tuned to exact harmonic specification, sometimes with two tones per bell. The difficulty in achieving these precise musical tones through **bronze casting** cannot be overstated; scholars of the Chinese Bronze Age are still not sure how this feat was realized [36]. In 1978, 64 bronze bells were found in the tomb of a nobleman named Yi (Figure 12), dating from about 450 BC. The largest bell weighs 203 kg and is 1.5 meters tall. The bells together allow a complete 12-tone scale to be played by a team of five to seven musicians [43].

In the Shang dynasty, bells were supported on a long pole and sounded by striking them on the outside rim with a wooden mallet (they didn't have clappers inside). From the Western Zhou period, it gradually became customary to suspend the bells mouth down from a shaft with a ring [15, 41]. An inscription of 123 characters is the longest on a single bell from the Shang or Zhou dynasties. The inscription relates that in the time of King Li, the state of Pu boldly invaded the Zhou territory. King Li fortified his borders and dispatched armies to repel the invaders. A peaceful resolution was achieved; in gratitude to the Emperor of Heaven and the deities for their divine protection, King Li ordered the casting of the Tsung-chou chung (Figure 12) [15]. The impressive, heavily cast Tsung-chou chung is ornamented on each side with eighteen conical studs, separated by bands of scrolling thunder patterns (leiwen), and surrounded by borders of fine thread relief. The flat underside of the bell is embellished with deeply cast scrolling spirals. The tubular shank is centered with a raised collar decorated with two taotie images [41].



Figure 12 – **a**) Tsung-chou Chung, late Western Chou dynasty, (800 - 700 BC); **b**) Tseng-hou-i pien chung collection of bells excavated at Tseng-hou-i, Hubei province [15]; **c**) Chime of twenty-six bells, H: 23.6-120.4 cm, Middle Spring and Autumn period (c. 550 BC), from Tomb 2 at Xiasi, Xichuan, Henan Province, excavated in 1979 [2].

## Jade

The Chinese word for jade, *yu*, includes many hard stones such as **nephrite**, **jadeite crystal** and **chalcedony**. The earliest jade objects in China are dated to 7,000 years ago, during the Neolithic period [44]. Along with the bronze vessels, many jade objects were also found in the burial tombs. Jade has had symbolic value in Chinese culture for thousands of years, and has been found in many eastern Neolithic tombs including **Dawenkou**. The process of shaping jade is time consuming and labor intensive. In addition to being a symbol of luxury and wealth, jade is associated with the qualities of purity and refinement and was believed to possess magical powers [45]. The beginning of jade production dates back to at least 3300 BC with the **Liangzhu** and **Hongshan** cultures (Figure 13) [46]; there are claims that jade production predates this by 3000 years with the Chinese and Japanese jade trade [25]. The jade manufacturing process required skills and the coordination of quarrying, cutting, sawing, grinding, drilling, polishing and engraving. Chert drills, grinding stones and unfinished jade products have been found together at burial sites along the southern bank of Yangzi River [47]. Nephrite was used by the ancients, while the use of jadeite didn't occur until the Qing dynasty (1644 – 1911 AD). Many of the skills acquired during this period were useful in the Bronze Age.

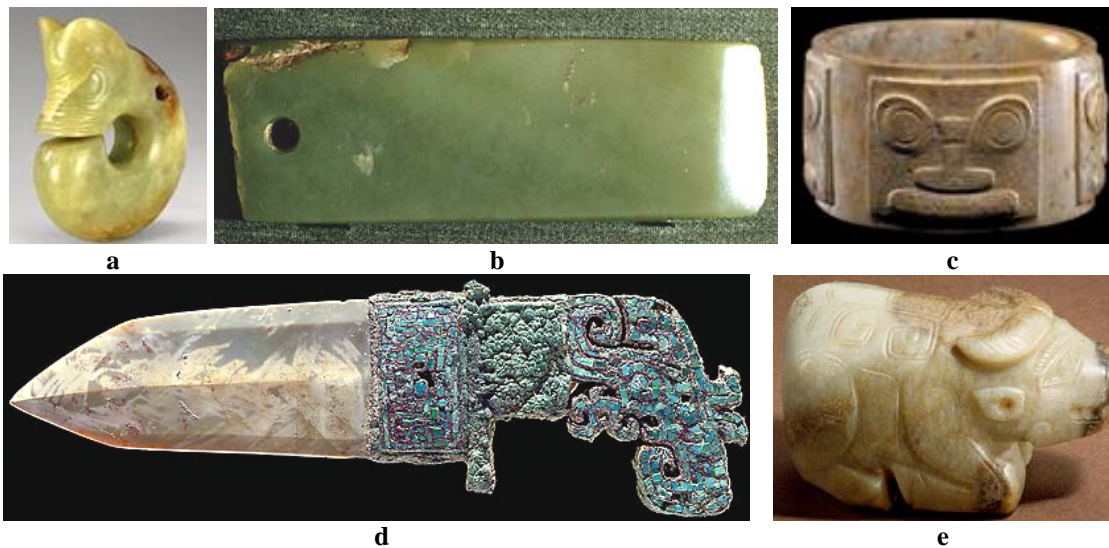


Figure 13 - **a)** Jade coiled dragon, Hongshan Culture (c. 4700-2920 BC), Liaoning Provincial Institute of Archaeology, Shenyang, National Gallery of Art, Washington DC [2]; **b)** Chisel blade, 3000 BC, Liangzhu culture, central eastern China, nephrite jade, L: 15.3 x W: 0.5 x Th: 1.0 cm [48]; **c)** Jade cong, Liangzhu Culture (3300-2200 BC) [2]; **d)** Ceremonial Ko Dagger, (1523 - 1028 BC), grey-green jade with white striations, bronze and green crystal inlay [43]; **e)** Jade Buffalo, Anyang 1300 BC [49].

## Bronze Age

The shapes of the early bronze vessels were very similar to the forms made with clay. The object's purpose was the same; the material used to make it had changed (Figure 14). Bronze artifacts began as passive imitation of pottery, but soon evolved into shapes adapted to the specific characteristics of bronze material. In design, the uneven and unbalanced nature of bronze vessels changed, and components of the vessel became more



harmonious. The number and variety of vessel forms increased through time, as well as the complexity of decoration and manufacturing techniques (Figures 15 & 16) [15]. These developments of increasing sophistication occurred alongside improvements in casting technology; it was more than mere familiarity with the bronze material, however. These advances included process planning, extracting, refining, bronze casting and experimentation with vessel form and decoration. In casting, for example, early bronze vessels were cast with only one pour. This technique was soon replaced with castings done in different stages with many parts that were later reassembled into one unit.



Figure 14 – bronze evolution from pottery: **a)** Bronze Wine vessel (Zuyi jiao), ~1000 BC, Shang dynasty, H: 23.9 cm, W: 18.6 cm, D: 10.9 cm [43]; **b)** Eastern Zhou bronze lei, 700 BC [50]; **c)** Bronze Lei, late Shang period, ~1300-1050 BC, H: 43.5 cm, D: 18.6 cm [51]; **d)** Bronze Cooking Vessel (Fuxin Ding), 1100 BC, Shang dynasty [43]; **e)** a pottery jiao vessel, ~2000-1500 BC [2]; **f)** Yangshao Funerary Jar (~2500 BC) Earthenware with painted spiral décor, H: 37.15 cm x W: 40 cm. [52] **g)** White pottery lei jar, excavated from Anyang, Freer Gallery of Art, (1200 BC) [43]; **h)** pottery ding, cooking vessel of Xia dynasty, 20.5 cm high, rim 20 cm diameter; unearthed at Erlitou [29].

FUNCTION	FOOD							
NAME OF VESSEL TYPE	ding	fang ding	li	xian or yan	gui	yu	dou	jue
STAGE OF DEVELOPMENT								
POTTERY PROTOTYPE								
EARLY SHANG								
LATE SHANG								

Figure 15 - Evolution of pottery and Shang bronze vessels [53].

WINE									WATER
JIA	HE	GU	ZUN	LEI	HU	YUE 1	YUE 2	FANG YI	PAN

Figure 16 - Evolution of pottery and Shang bronze vessels [53].

Decoration began as thin lines in low relief, but soon changed to broader, deeply incised lines, and finally combined the use of different levels of decoration on one vessel. The single band of decoration common in the early time period also became multi-banded and many tiered. To produce these different kinds of decoration, the motif was carved directly on the mold. The most popular animal image of the Shang was the **taotie** monster mask (Figure 17). This beast of gluttony combines many animal characteristics into one ferocious creature with piercing (often bulging) eyes that stare out from the Shang ritual vessel [3, 4, 15, 36, 26, 54]. It uniquely communicates the religious and ritual spirit of ancient Chinese bronze vessels. The taotie was insatiable, capable of swallowing a man in a single gulp that eventually met with disaster when an unfortunate victim got stuck in his throat [15].

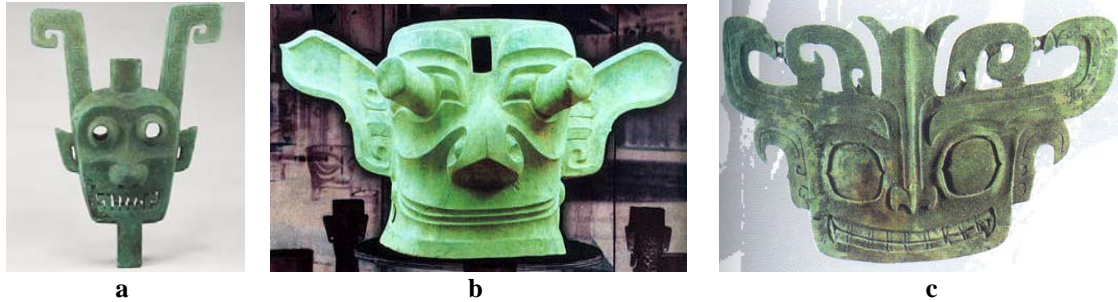


Figure 17 – **a)** bronze mask from Jiangxi (c. 1200-1050 BC) Jiangxi Provincial Museum, Nanchang [55]; **b)** Mask with protruding pupils (~1100 BC) excavated from Sanxingdui Pit #2 [28]; **c)** bronze animal face with taotie pattern from Sanxingdui [28].

After the Western Zhou period (1100 - 771 BC), bird designs were common decorative motifs and symmetry was still maintained. After the mid and late Western Zhou period, chain link patterns, fish scale patterns and wave patterns for the most part, replaced animals as subject matter for the main design of bronze vessels. After the mid-Spring and Autumn period (770 - 476 BC), the most frequently used design was a vertically interlocking geometrical animal band design [3, 4]. The techniques used in executing the various bronze designs went from the engraved lines and embossed designs used in the earlier periods, to deep relief and three dimensional sculpture like designs, and eventually even to inlaid designs. Materials used for inlaid work included gold, silver, copper and turquoise (Figure 18) [3, 4].



Figure 18 - Erlitou Culture, bronze plaque inlaid with turquoise, Gedangtou, Yanshi, Henan Province, 16.5 cm pendant [56]; Bronze oval bowls with turquoise, gold foil and wire inlays, H: 10.4, D: 17, (300-400 BC) [57].

**Gold and Silver Inlay** was a common bronze decorative technique used after the mid to late Spring and Autumn period, and was developed from the inlay technique where a trough is gouged out of the material and gold thread or foil is carefully pressed in with special tools and polished (Figure 19). During restoration of the masks found at the Sanxingdui excavation sites (Figure 19b) it was possible to examine how the masks were attached. It appears that a lacquer based material was used for adhesion, and an unidentified white powder was found between the gold and lacquer [5]. Although it was used mainly on bronze weapons, chariot fittings and mirrors, it was also found on a few ritual vessels [15]. These artistic and technological improvements were in response to the demands of ancestor worship rituals for the high ranking elite; previously jade, ceramic



and lacquer ware had been used in burial ritual since the Neolithic period. Bronze, when it finally did appear in burials, was at first relatively rare, but gradually surpassed jade weapons and ceramic vessels [15].



Figure 19 – **a)** Bronze inlaid with gold, tiger devouring a deer, Tseng collection, CSUN, Warring States Period. **b)** Bronze human head with gold leaf, Late Shang Period (c. 1300-1100 BC) excavated from Sanxingdui Pit #2, H 42.5 cm [2]; **c)** bronze inlaid with gold and silver rhinoceros zun, unearthed from Maoling, Xiping County, Shaanxi Province in 1963, Western Han dynasty, (206 – 23) BC, H: 34.1 cm, L: 58 cm [29, 44].

In Neolithic times, people had made tools out of stone for hunting and gathering food. As early as 10,000 BC, raw copper was being pounded into tools and ornaments. However, alloying metals (adding **tin, lead, arsenic, titanium, magnesium and cobalt** to copper) to harden the material and lower the smelting point occurred much later in history [26]. In China, the Bronze Age is assumed to have started around 1900 BC, although the earliest dated bronze object in China, a knife cast from a mold found in **Gansu province**, is from about 3000 BC [42] and other examples are from the **Majiayao Culture** in northwest China, same time period [47]. This preceded the onset of the Bronze Age in the Middle East by several hundred years. In Greece, bronze use began around 3000 BC. The pre-Columbian civilizations of the Americas had no bronze technology until about 1000 AD. In Africa, stone was directly replaced by iron technology, and the Bronze Age was bypassed completely [26, 58]. British Bronze Age lasted from 2500 BC to 1000 BC [59].

The Chinese learned how to mine and **smelt copper** and tin to make weapons and tools; this required an organized labor force and skilled craftsmen. The high level of workmanship seen in the bronzes in Shang tombs suggests a stratified and well organized society with powerful rulers who were able to mobilize human and material resources to mine, transport and refine the ores, to manufacture and tool the clay models, cores and molds for casting and to run the foundries. Bronze became widespread in the central plain of China in early Shang times. It is believed that the high temperatures of the Neolithic kilns used to fire **pottery** were hot enough to melt metals from stone. For this reason, scholars believe Chinese artisans were able to develop bronze without the influence of other cultures [36]; the evidence suggests an **independent Chinese discovery** of bronze [26, 42]. The Shang dynasty capital at Anyang was close to the most **abundant deposits of lead, copper and tin in China** (Figure 20), and bronze making apparently spread from there to the rest of China [42]. By the Bronze Age, they could farm and produce additional food to sustain miners, bronze smiths, weavers, potters and builders. Bronze was produced on a massive scale for ritual objects and weapons used by the ruling elite.

These Chinese believed the king's right to rule was based on relations with his ancestral spirits (who controlled his fate). The king was also responsible for placating the great forces of nature (the sun and rain gods) that controlled the outcome of harvests. For these gods and spirits to look favorably on his kingdom, the king would make regular sacrifices of wine and grains that were placed in elaborate bronze vessels and heated over the fires on the temple altar. Bronze was related to power and divinity. Bronze vessels were symbolic of royalty and were central in ancestor worship and state rituals [26]. So it is not surprising that **religious rituals, not war, inspired the further development of bronze casting** in Shang China.

Archeological excavations in the mining center of **Tonglushan**, near the city of Daye in Hubei Province, have revealed important historical information concerning mines that were active during the Chinese Bronze Age. An enormous mine (2 square kilometers) with smelting facilities roughly 3,000 years old was discovered on Mt. Verdigris [42]. At this site, near the Yangtze River about 20 km southwest of Huangshi, more than 400,000 tons of ancient slag and high grade copper deposit were found. Further excavation unearthed tools made of bronze, iron, bamboo, wood and stone; also uncovered were more than 100 separate diggings and dozens of smelting furnaces. The total length of the trenches and shafts has been estimated at 8,000 meters; this would result in roughly 80,000 to 120,000 tons of copper extraction from this area [60].

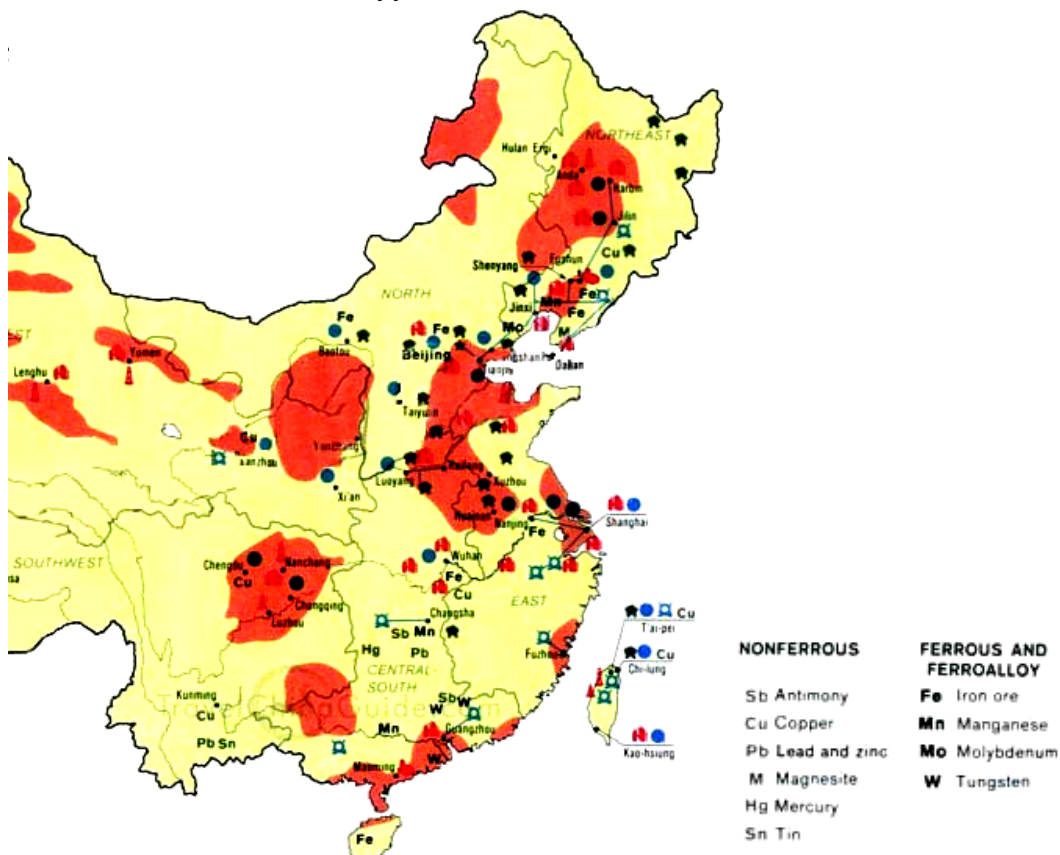


Figure 20 – Map shows metal rich areas (Fe, Sb, Cu, Sn, Hg, Pb, Mo, W, Mn) in China [8].

After 1300 BC, bronze ware was predominantly used in complicated sacrificial ceremonies. The bronze vessels at that time were made with much thicker walls and in larger sizes. Ho Mu Wu Dafangding or (Si Mu Wu), a square Shang ding, is the largest (133 cm H x 110 cm L x 79 cm W) and heaviest (1,925 pounds or 875 kilograms) bronze metal casting yet discovered, from anywhere in the world dating to the second millennium BC [29]. This cauldron was large enough to cook two oxen. Some dings were used for boiling people as a means of execution. The Duke of Ai from Qi was reported to have ended his life in a ding during the third year of king Yi (Zhou dynasty) [61].

Casting large objects was not easy; it required large crucibles and efficient furnaces. Casting some of the largest objects required coordinated melting in many crucibles similar to a **modern factory**. A puzzling aspect about the quality of the Shang bronzes is that they are so impressively large, that some scholars feel there must be an earlier bronze culture not yet discovered. However, the Shang metallurgical tradition probably arose very quickly from pottery making. The Chinese made porcelain in Neolithic times; pottery kilns found near **Xi'an** could maintain temperatures at **1400 °C** as early as the 6th millennium BC, more than enough to melt copper. Shang “metallurgists” did not use stamping or engraving or hammering in their work; most likely, casting was used exclusively [42]. The Shang pottery industry was highly advanced; they could easily reach the high sustained temperatures that made smelting and casting relatively easy. The Western tradition of hammering metalwork and the Chinese tradition of casting it (at least from Shang times onward) were very different techniques. The Chinese became more sophisticated bronze metallurgists than those in the West. The famous terracotta army of the Emperor Qin (~220 BC) has bronze weapons that have been deliberately **alloyed with titanium, magnesium and cobalt** to give superior hardness [42].

Chinese Bronze Technology has been divided into **five stages of development** (Figure 21) [62]. Around 1800 BC, a **Primitive stage** began with the making of bronze wine vessels similar to those found at Erlitou (the **Xia** culture was noted for their black lacquered pottery). In 1600 BC, a **Formative period** began and was marked by development in both shape and vessel assembly. Some of the light weight, food vessels (**dings**) with animal mask designs are representative of this period. The early Shang objects differ from Xia period vessels in that many bear crude animal mask designs that are very abstract and exaggerated. Bronze vessel shapes underwent major developments in the mid-Shang period. The most representative vessels of this period are the **zun** (Figure 6); other wine vessels included various types of **hu** with movable handles (Figure 51). Characteristic too, are some lidded vessels cast with loop handles [38].

A **period of brilliance (or the Florescent period)** from 1300 to 900 BC, marks a high point in the evolution of Chinese bronze art. Late Shang bronzes are highly regarded and considered one of the most outstanding achievements of ancient Chinese civilization. Taking historical conditions and the particular characteristics of these periods into account, it ranks highly with anything accomplished in latter times. Today, some 3000 years later, these bronzes are still admired [38]. During this time the stability of central political power encouraged rapid economic development [38, 62]. This is reflected in the material culture of the time and by the wide range of bronze types. Bronze art of this

period had more realistic animal designs with religious overtones. Usually inside each vessel was inscribed the owner's clan name and the name of the ancestor to whom it was dedicated. A few vessels also have inscriptions that record significant dates. Bronze ritual wine vessels were already in existence, wine was common in Shang sacrificial activities. New vessel shapes emerged (Figures 15 & 16) and old shapes were modified. The **ring foot**, a major advance in casting technology, was used to ensure that the core and the outer mould were aligned properly (Figure 22) [38]. In the late **Shang** period, differences appear in the use of bronze in burials, differences that appear to accompany a new perspective on mortuary ritual. In earlier times bronze burial objects were elaborate and highly decorated in the tombs of the high ranking elite, but in the late Shang period, the elite began to use simple (unornamented) mortuary vessels [15].

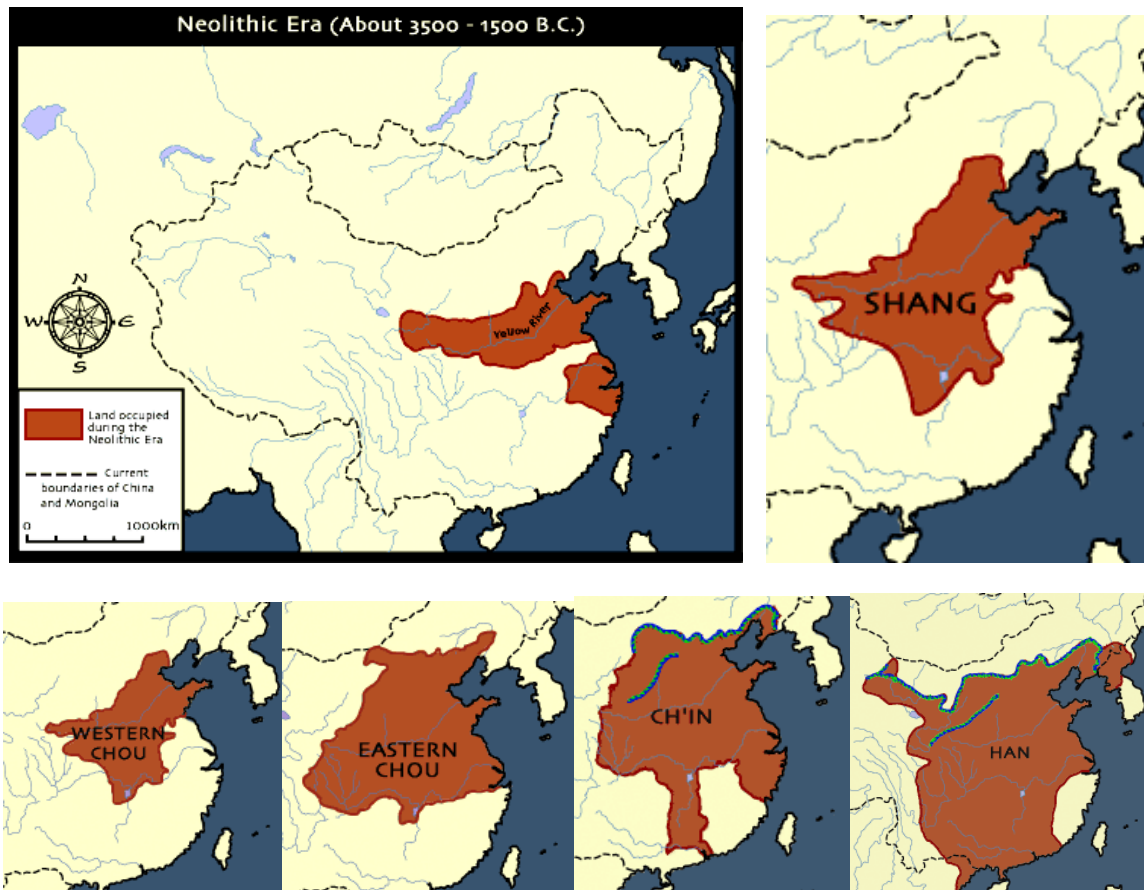


Figure 21 – Area occupied during the Chinese dynasties after the Neolithic Era beginnings along the Yellow River [63].

The 11th century BC saw the beginning of the Western Zhou culture that was not as highly developed. They lacked the necessary technology to create innovative bronze art; the majority of vessel shapes and decorative styles followed Shang customs. There was a gradual decrease in the range of wine vessels, and some increase in the range of food utensils. The Zhou people placed greater emphasis on the value of **inscriptions**. Zhou inscriptions describe in detail the owner's identity, status and the good standing of his family. Many inscribed vessels were displayed in the ancestral temples of their owners



and were regarded as sacred. Often these inscriptions contained information important for its historical context; some Western Zhou bronzes owe their notoriety more to the content of the inscriptions cast on them than the artistry of their design (Figure 23) [38].



Figure 22 – (left) San P'an Basin, late Western Zhou dynasty (~ 700-800 BC); bronze pan, height: 20.6 cm, rim diameter 54.6 cm, weight: 21.3 kg; (right) Ring foot of this pan is decorated with kui dragon patterns [15].

Techniques were varied at the foundries, but most inscriptions were prepared in a clay mold and then cast on to the metal surface of an object. Most inscriptions are countersunk and positive. To obtain a positive inscription, the surface of the mold was prepared with the text in a negative form; the text was written with a stylus on a surface of wet clay. When hardened, this positive version could be pressed into a new supply of wet clay to provide a negative relief. The hardened clay of the second version in negative could be trimmed and fitted as a block into an excavation on the mold core of the complete vessel. The mold and this fitting were then ready for the molten metal that would form the inscription back into a positive appearance. This method requires the least number of steps to cast a countersunk, positive inscription and allows for the text to be written out freehand the way it will ultimately appear [56, 64].



Figure 23 – Much information comes from ancient text and documentation, but the most important source is from inscriptions that were cast onto the bronze [15]. Shi Qiang bronze pan, Western Zhou Dynasty, ~900 BC, Fufeng [2]; enlargement of inscriptions from Shi Qiang pan [65].

The **Shi Qiang pan** (Figure 23) is one of the most important Western Zhou bronze vessels due to its **270 character** long inscription. In two columns, it provides an outline of the first seven Western Zhou kings with a similar account of four generations from the Wei family [65]. In both shape and decor, the **San p'an** (Figure 22) reflects the succinct

and principled style characteristic of late Western Zhou bronzes. The lower side of this piece is decorated with kuei dragon designs and animal heads in relief, animal mask patterns cover the high round base. One of the most remarkable features of this bronze is the **350 character inscription** cast on the inner surface [15]. As characteristic of late Western Zhou inscriptions, it is enclosed by straight bordered columns cast in relief. On the **Mao Kung Ding** (Figure 24) interior is an inscription of **497 characters** extending from the mouth of the vessel to the bottom interior. The inscription is the imperial mandate for casting the vessel. Duke Mao ordered the casting of this ding with the longest inscription among bronzes yet unearthed [3, 4, 54]. Its inscription predates historical accounts of the Western Zhou in the Shang-shu (Book of Documents), making it one of the most important records of this period and an invaluable treasure. Between the characters of the inscription are checkered patterns cast in light relief, as is characteristic of bronze inscriptions from the middle to late Western Zhou period. The Mao Kung Ding was excavated in Shensi province in 1814 [15].

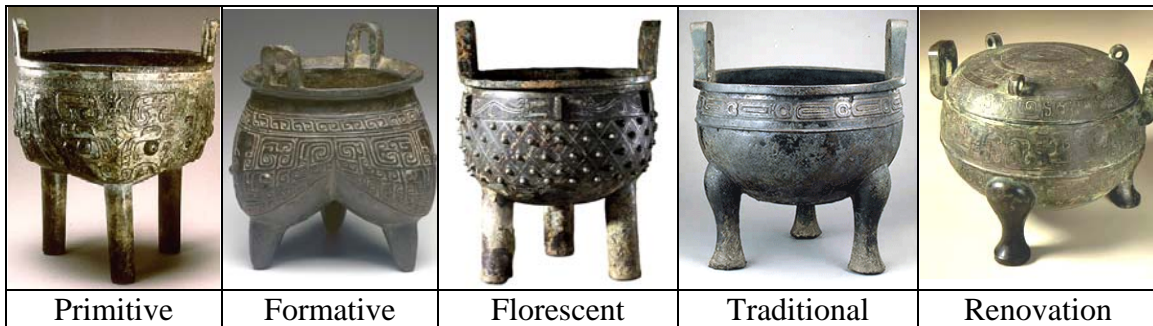


Figure 24 - Comparison of bronze periods; **Primitive:** Shang bronze Li Ding, c. 1500 BC [43]; **Formative:** Tripod Ritual Vessel, Bronze, H: 16.83 cm x W: 13.65 cm x D: 14.42 cm, (1200 BC) [52]; **Florescent:** Bronze ding (ritual food vessel), Shang dynasty, 1100 BC [59]; **Traditional:** **Mao-kung Ding**, late Western Zhou, is a 2,800-year-old bronze ritual vessel [15]. **Renovation:** Cast bronze, lidded ritual food cauldron (**Lidow ding**) with interlaced dragons, Shanxi Province, ancient state of Jin, 34.2 cm x 39.3 cm, (c. 500-450 BC ) [66].

**A Traditional Period** began in roughly 900 BC and lasted until 500 BC with the waning influence of Shang culture. The **Zhou** people, after a century of development in the early Western Zhou period, completed the process of reforming and developing Shang bronze art to embody particular Zhou features. During this period, subtle beauty was transformed into imposing simplicity. Fewer wine vessels were produced and some (Jia, jue, zhi and gu) vanished completely. In 771 BC the declining Western Zhou dynasty came to an end. King Ping of Zhou moved his capital to present day Luoyang. During this **Spring and Autumn period** each of the feudal states had its own **bronze casting industry**. The vessel shapes of the late **Western Zhou** continued to be used, but a few exhibit special regional characteristics. These vessels, neither ancient nor modern in style, were made by the **Yue tribe** from Southern China, who admired the culture of the Central Plains and cast vessels in imitation of ancient styles that also had pronounced regional characteristics [62, 66].

The final stage of the Bronze Age, the **Renovation period**, was from 500 to 200 BC. Slavery had been replaced with a feudal system and with the social and cultural changes,



the manufacture of bronzes increased. New styles, exquisite workmanship and elaborate decorations were prevalent features. The ding, a three legged ritual vessel was used to present food to ancestral spirits and was also used as a ground ornament. Fantastic creatures, symbols, even written characters recording ritual procedures were cast into the ding's surface [66]. In its typical Shang form, the ding was a sturdy vessel mounted on straight legs. By the time of the Eastern Zhou dynasty, the ding had acquired the refined form of the Lidow ding (Figure 24). It had also been secularized; although the Shang tradition of burying bronzes with the dead continued, they were now presented as state gifts to foreign rulers and handed down as symbols of family honor and status [66]. The Lidow ding is related in terms of style to the bronzes discovered near the village of Liyu (northern Shanxi province) in 1932. It displays the high level of bronze casting attained by Eastern Zhou metal smiths despite the anarchy and constant warfare that plagued the period [66].

### Ancient Metallurgical techniques

About 5,000 years ago, people were extracting **brass** from ore to make small objects with a **cold forging** technique [40]. The copper sulfide ores mined deep in the caverns had impurities. Smiths were inadvertently smelting a mix of copper ores that contained small amounts of arsenic, tin, zinc, antimony and nickel. These alloys were still dominated by copper, but had a lower melting point than pure copper. Oddly, the impure copper ore resulted in a greater variety of alloys and improved castings. By trial and error, ancient smiths would begin to associate a particular mixture of ores with a specific product [42]. In the Shang Dynasty, bronze **smelting** (Figures 25 & 26) became an important industrial branch. Smelting produces a blob of metal (called **bloom**) ready for casting [58, 67]. The Chinese began adding small amounts of tin to lower the melting point and increase solidity. **Tin** gave **brass** a bluish tinge, and the alloy became known as **bronze**, which means **bluish copper** in Chinese [40]. The smiths learned that 85-95% copper combined with 5-15% tin resulted in bronze, an alloy that is harder than copper, but melts at a lower temperature (950 °C vs 1084 °C for copper). Zinc (alloyed with copper makes brass) or nickel are rarer and much more difficult to smelt, and antimony/copper alloys are brittle [42].



Figure 25 – Drawings of ancient Chinese casting process [15, 68].



Figure 26 – Engraving from the Numismatic Museum in Beijing, China showing the metallurgical techniques used to manufacture coins.

Similar to antimony, arsenic added to tin and copper (up to 3%) produces a harder final product. Arsenic fairly routinely occurs as an impurity in early bronze, and small amounts of it were probably not intentional. By the time the proportion of arsenic in bronze reached two or three percent, however, the effects are quite noticeable and presumably intentional. Mixing lead into the copper tin alloy produces **lead bronze**, and may contain as much as 10% lead. The lead in the alloy does not become part of its crystalline structure, increasing the compound fluidity when it is in its molten state; this facilitates casting, particularly the casting of finely detailed objects. However, lead bronze is softer than normal bronze, and less able to hold a cutting edge, making it less ideal for tools [58].

A few very early **chipped stone** tools were made from metal ores that had been pounded to chip off pieces. It was also possible to reshape the raw ores into functional tools by pounding, heating and working the metal. Over the centuries, smiths have used a range of techniques to process metal [58]. Softer metals, including copper and bronze, can be shaped through **cold hammering**, especially after smelting to remove impurities. Because hammering is harmful to the crystalline structure, hammered metal becomes more brittle; the crystalline structure can be restored by annealing, a process of successive heating and slow cooling [58]. The method of heating and metal hammering, prevalent in Europe, was used in the early period, but was not common in ancient China [15, 47]. However, miniature bird, fish, animal or leaf shaped ornaments were made from very thin (0.1-0.2 mm) **hammered** sheet bronze [5]. Enormous quantities of copper and tin must have been mined, refined and transported to meet the demands of the Chinese ruling elite. Casting techniques require more quantities of metal than the hammering method; the molds and cores couldn't be removed as a whole after cooling [26].

The power of the Erlitou culture though widespread was succeeded by the Erligang culture and then around 1200 BC by the Shang rulers at Anyang. Erligang expansion carried the bronze industry to other regions. Archaeologists consider Erlitou, Erligang and Anyang as successive stages of a continuous cultural tradition centered in the Zhongyuan and identified by their tradition of bronzes. Large scale bronze metallurgy

was seen at Erlitou in the Henan Province [5]. Its bronze industry centered on the production of ritual vessels **cast in clay section molds** of two or more parts. The section mold technique was seen at the Erlitou site as early as 1500 BC [5]. The bronzes found at Sanxingdui looked dramatically different than the ritual vessels, yet were cast using the same techniques [5]. Heavy reliance on casting and on section mold casting in particular, distinguishes the bronze industry of the Erlitou, Erligang and Sanxingdui. Technologically, multi piece mold methods also marked the departure of metallurgy at Erlitou from the surrounding regions. Instead of relying on hardening metal by cold working, softening it by annealing, or casting it with single or double stone molds, artisans made a bronze vessel to fit a specific application by changing the physical properties of the metal (developing bronze alloys of copper, tin and lead), and by using a sophisticated assemblage of clay inner and outer molds [69].

In the **Zhongyuan** foundries, mold making was greatly complicated by the elaborate decorations and necessitated many mold part assemblies. For the Sanxingdui, they constructed complex shapes from pieces cast separately in simple molds and later joined the components. From the Erligang period, founders in the Zhongyuan commonly joined two pieces of metal while casting the second piece. These standard techniques enabled them to make elaborate shapes. The casting that produced the bulk of the object was the **main pour**. A small part made before the main pour could be embedded in the mold in to lock them together; this was considered **precasting**. Parts could also be **cast on** after the main mold. In rare cases, two large objects were joined together by casting a smaller piece between them (called **running on**) [5, 67]. There is evidence of brazing and **soldering** during this period. For example, the masks found at Sanxingdui were cast with holes on each side of the head. The ears were cast later, inserted into the holes and attached by **soldering**; the solder is visible from the interior wall of the mask (Figure 27) [5]. The mask with protruding pupils seen in Figure 27 was cast in six pieces, five (2 ears, triangular underside of nose, 2 pupils) were precast and embedded in the final mold. The mold for the main pour required a rear section (or core) and one or two sections for the front of the mask [5]. The square/rectangular shaped cutouts on the forehead and lower jaws were for attaching large projecting ornaments.



Figure 27 – bronze masks with soldered ears, 1100 BC, excavated from Sanxingdui Pit; both masks are roughly 20 cm tall by 40 cm wide [5].



## Casting technology

The ancient Chinese developed a most unusual casting method called the **piece mold process** (Figure 28). In the piece mold technique, surface decoration could be made by carving into the mold (for raised relief) or into the model (for recessed designs). The use of a ceramic mold made of tightly fitting sections made it very difficult to use intricate shapes. As a result, greater attention was placed on surface decoration, which was easier to create [27]. A model of the item to be cast in bronze was sculpted out of clay and decorated with patterns and inscriptions. Around this model, the ancients packed clay to create a mold; the clay formed a negative impression of the shape and decoration. The model was fired and the clay was removed in sections to form the piece molds. Subsequently, these sections were reassembled and reinforced with more clay and the necessary cores for the inside, base and legs. During the pouring of the molten bronze, air could escape through special channels. After cooling, the mold and cores had to be removed to free the vessel. Very little finishing was required because of the great accuracy with which the models and molds were made [15, 26]. During the Shang and Zhou dynasties, piece mold casting was the dominant technique.

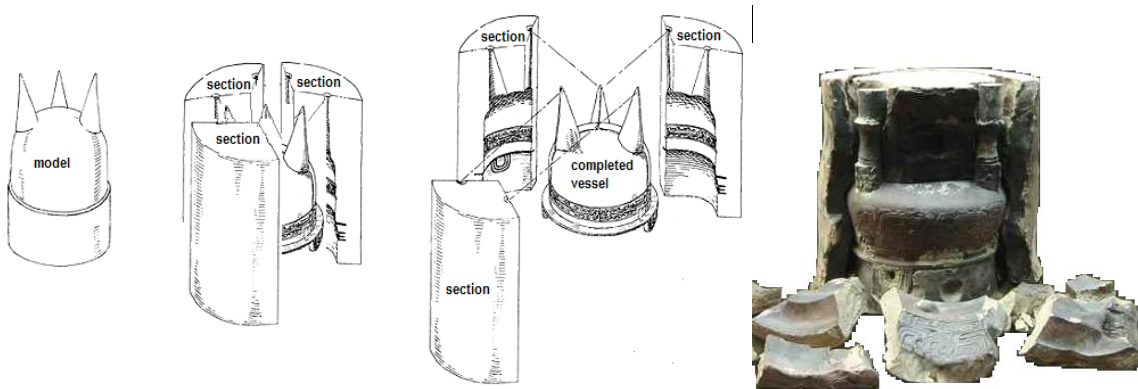


Figure 28 – Diagram showing a clay piece mold for making a bronze vessel; an actual casting [1, 15, 70].

Bronze technology reached a peak around 770 to 476 BC [15, 40]. A specialized metal casting method called the **lost wax technique** was sometimes used in conjunction with the **piece mold process** (Figure 29). The procedure required the object to be sculpted in wax, covered with clay, dried and then baked in a ceramic kiln; subsequently the wax melts, leaving a space where the molten metal could be poured. When the metal solidified, the clay was broken away, leaving a metal replica of the wax sculpture. To form a hollow object instead, wax was sculpted over a clay core, resulting in a hollow metal object. Because the clay mold is destroyed in the lost wax process, the method is not suitable for mass production, but is good for very detailed objects [58]. The lost wax method was commonly used in the **Sanxingdui** region. The advantage of this method over the piece mold technique is that small irregular objects can be made since wax is relatively easy to shape and the mold is seamless.

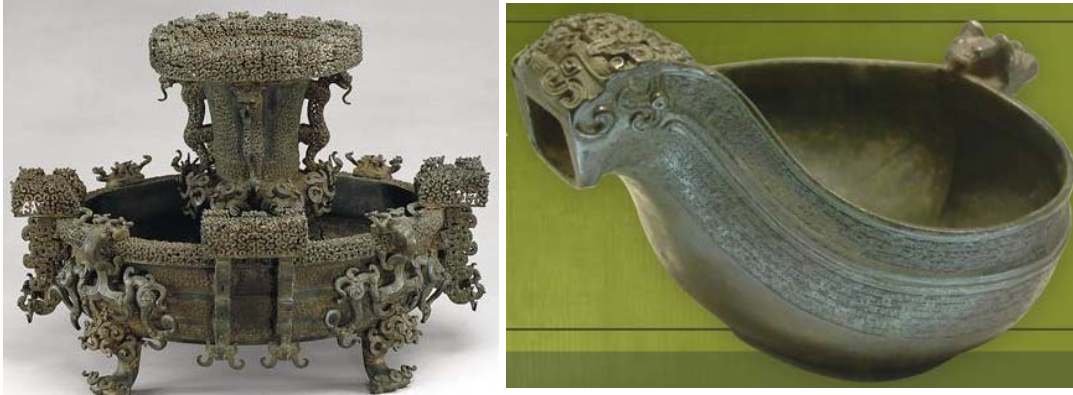


Figure 29 – bronze wine vessel with elaborate pan, Warring States Period (c. 400 BC) combine piece mold and lost wax technique [2]. Wang-tzu, lost wax technique, Warring States Period, H: 12.8 cm, Wt: 1.3 kg [15].

**Composite Casting** is a subtype of piece mold casting that first appeared in the early Shang dynasty. The technique was used to attach small appendages, such as handles, to a larger vessel. Appendages were cast first, and then placed within the mold for the still uncast larger vessel. When molten bronze was poured into the primary mold, it anchored the pieces in place. The technique enabled the production of larger vessels and also facilitated the sculpting of more vibrant appendages [15]. As casting techniques became increasingly sophisticated, artisans began to disguise the seam lines by elaborating them into high relief **flanges** (Figure 30). The flange is one of the best examples of the intersection between form and ornamentation in the art of bronze casting [15].

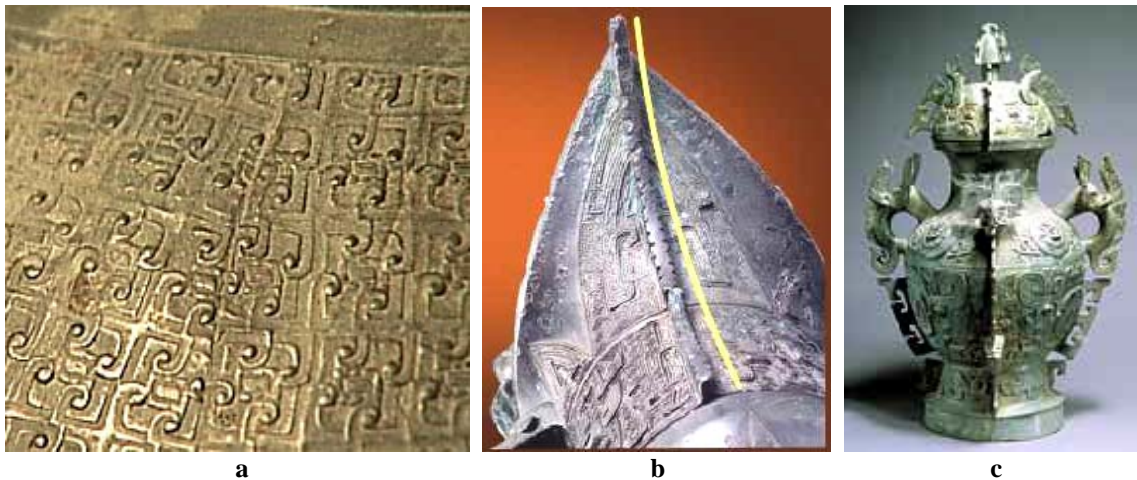


Figure 30 – **a**) Bronze mold with visible seam line (~400 BC) [71]; **b**) seam lines exaggerated into raised flanges (late Shang dynasty) [15]; **c**) Lei with elephant shaped handles, bronze, Western Zhou, (~800 BC), H: 69.34 cm x D: 21.84 cm [72].

The Six Basic Alloy Formulas for bronze composition has variable interpretations mostly due to the definition of the Chinese characters "chin" (metal) and "hsi" (tin). Some scholars believe that the character **chin** refers only to pure copper and the proportion should be 6 parts copper to 1 part tin. If the translation refers to a bronze alloy, then the proportion of copper to tin would then become 5:1. The character for tin also presents

some problems in the interpretation. Most scholars agree that it refers to pure tin, however, some believe the term includes tin and lead. Table 1 shows the alloy proportions according to the two interpretations. In the bronze and reflector formula, tin and copper are used in equal proportions for one of the translations; however, if the tin content is too high, the alloy will be brittle. According to the scholar Chang Tzu-kaio, an omission in the original Chinese may have led to an incorrect formulation [15].

Table 1 – Variable interpretation of bronze alloy composition [15].

	“Chin” = <b>pure copper</b>	“Chin” = <b>bronze alloy</b>
	Copper: tin	Copper: tin
Bells and Cauldron Formula	6 : 1	5 : 1
Axe Formula	5 : 1	4 : 1
Halberd Formula	4 : 1	3 : 1
Blade Formula	3 : 1	2 : 1
Whittler and Arrow Formula	5 : 2	3 : 2
Bronze and Reflector Formula	2 : 1	1/2 : 1/2

Iron is one of the most common (and cheapest to mine) metallic elements on the planet. It was not until about 1200 BC that iron production of tools occurred; the high temperatures needed to process ore exceeded ancient kiln technology [73]. Pure iron has a melting point of 1,535 °C; the limit of an ancient furnace may have reached **1400 °C**. (By contrast, copper has a melting point of 1,083 °C, and ancient pottery kilns could reach temperatures in this range, but it was rare to get far above it.) It was eventually discovered that the introduction of three to four percent carbon to the mixture could lower the melting temperature (to as low as 1,150 °C). Unfortunately, carbon also contributes to brittleness [58].

### **Tseng collection at CSUN**

Several of the artifacts in the Tseng collection were examined in the Advanced Materials Laboratory at California State University Northridge (College of Engineering). Most of the samples were too large to directly place in the chamber (Figures 31) of a JEOL JSM-5800 Scanning Electron Microscope (SEM) and could not be made into smaller (damaged) samples, so carbon tape was used to remove surface deposits for analysis (Figure 41). The Chinese objects included a **bronze vessel with jade dragon handles** and a **copper/gold lid** (Figures 33, 38), a **bronze guang** (Figure 41) with animal characteristics, and a **bronze ding** (Figure 45). For each sample, micrographs (photo images) were taken, spectrum analyses were obtained and elemental compositions were calculated (Figure 32). The results can be seen in Figures 34-37, 39-40, 42-44, 46-51.



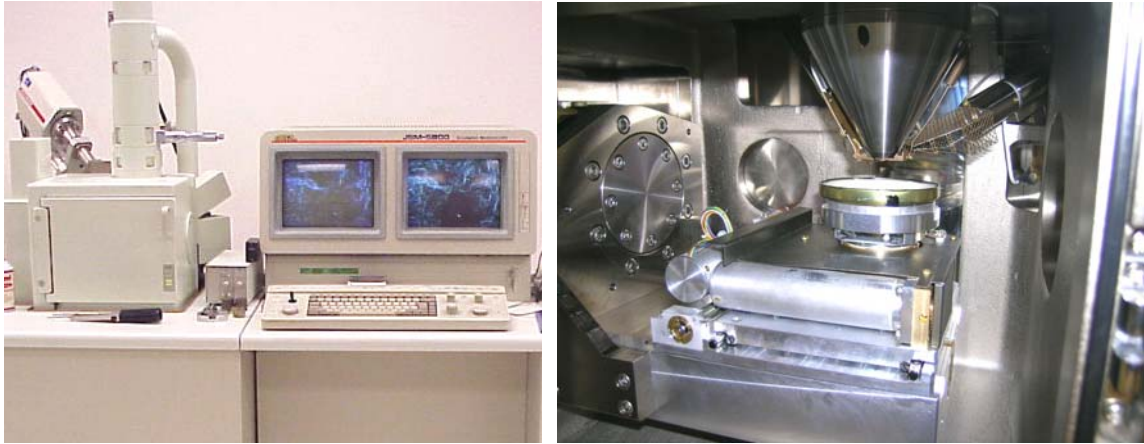


Figure 31 - JEOL JSM-5800 SEM with energy dispersive x-ray analysis (EDAX) and inside chamber.

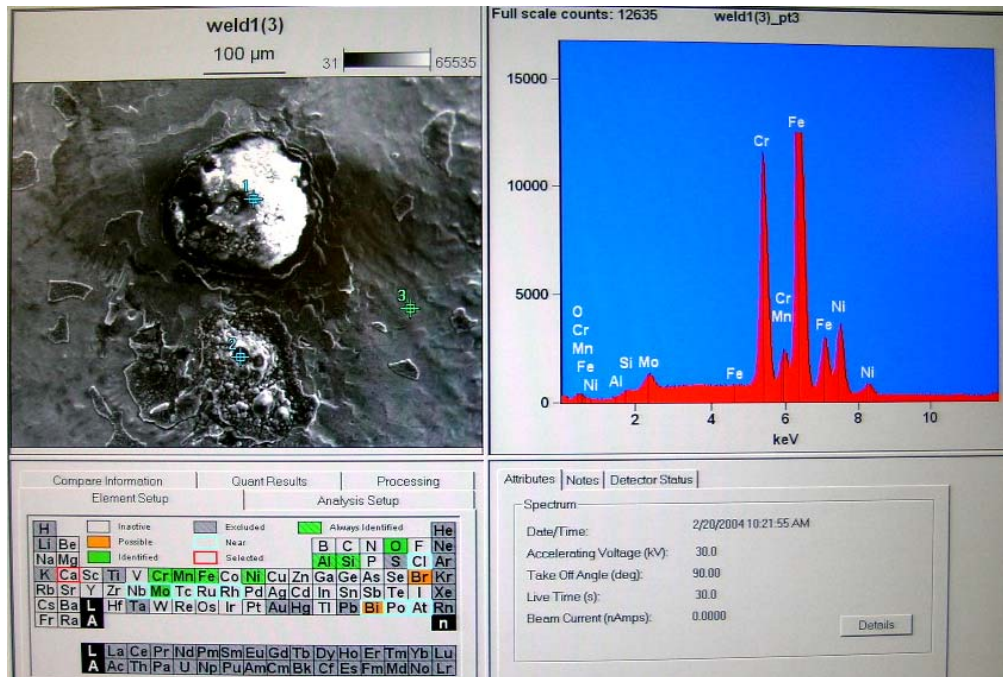
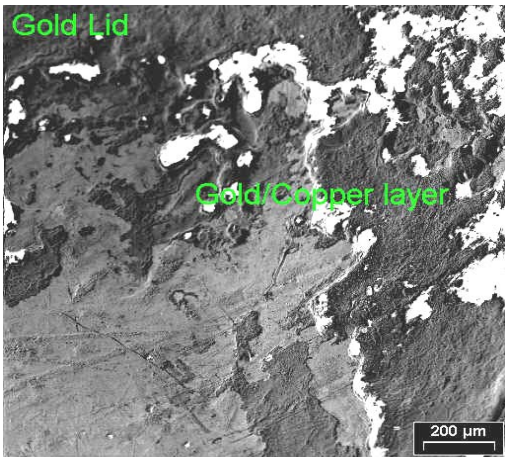


Figure 32 – Noran System Six software can display high resolution image of sample area, spectrum and elemental composition.



Figure 33 – Jade dragon cast in bronze with (10 petal) flower lid. The copper lid is gilded and vessel is detailed with gold frogs. Dragons on side are far more detailed and sophisticated than dragon on lid.



Element	Intensity	K ratio	W%	A%
O	0.7	0.00129	0.44	2.29
Al	4.5	0.00270	0.67	2.06
Si	1.6	0.00106	0.18	0.53
Cl	5.1	0.00374	0.57	1.35
Ca	1.4	0.00130	0.15	0.30
Cu	222.2	0.64114	58.66	76.85
Au	20.5	0.31998	39.34	16.63
		0.97098	100.00	100.00

Figure 34 – SEM micrograph of lid; Quantitative Energy dispersive analysis with X-ray emission (EDAX) results show predominantly copper (76.85 atomic %) composition with some gold (16.63 atomic %) and other elements.

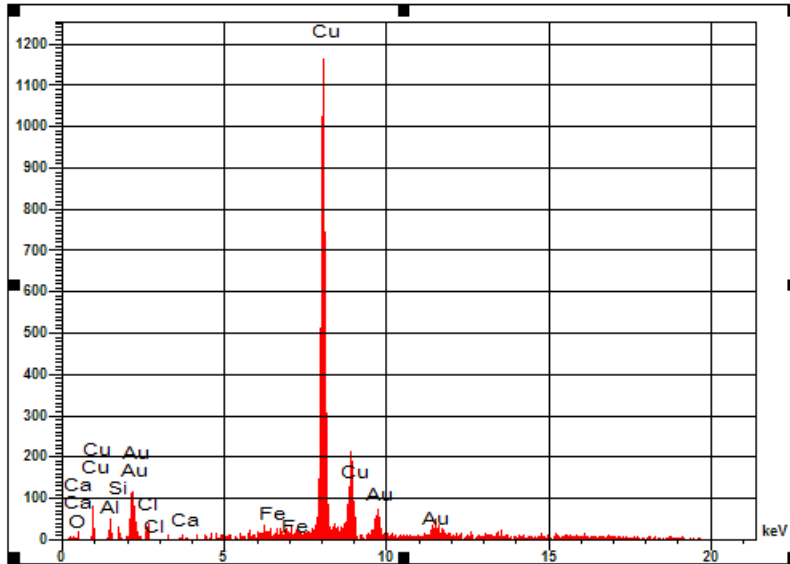
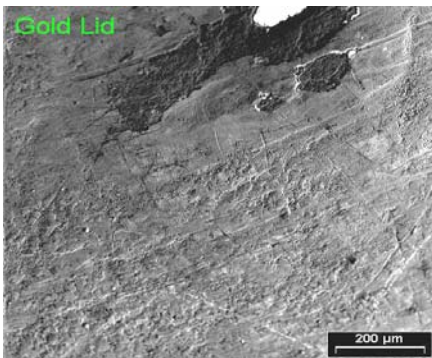


Figure 35 – EDAX spectrum showing peak intensities (count rate) for various elements; copper has the largest peak.



Element	Intensity	K ratio	W%	A%
<b>Cu</b>	150.4	0.11299	8.95	23.36
<b>Au</b>	218.3	0.88424	91.05	76.64
		0.99704	100.00	100.00

Figure 36 – SEM micrograph of lid from gold area; Quantitative EDAX results show predominantly gold (76.64 atomic %) composition with some Cu (23.36.63 atomic %).

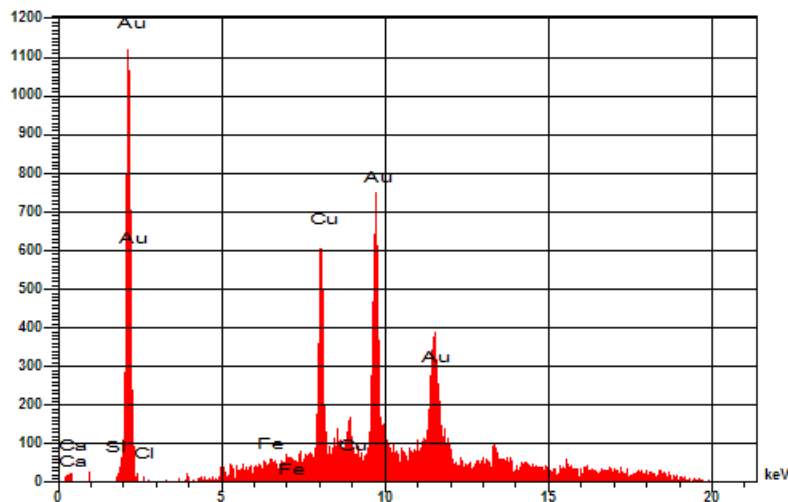


Figure 37 – EDAX spectrum of lid showing peak intensities (count rate) for various elements; gold (Au) has the largest peak.





Figure 38 – Jade dragon artifact with clay deposits.

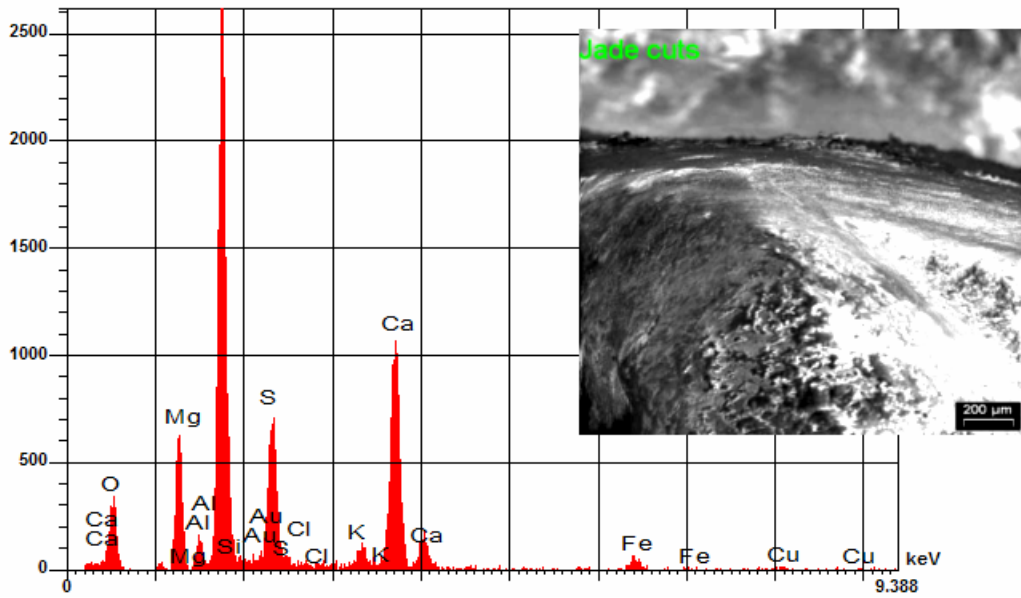


Figure 39 – Jade dragon SEM image and EDAX spectrum showing presence of silicon, calcium, magnesium and sulfur.



Element	Intensity	K ratio	W%
<b>O</b>	37.9	38.19	54.44
<b>Mg</b>	67.0	8.12	7.61
<b>Al</b>	15.4	1.65	1.40
<b>Si</b>	328.4	29.59	24.02
<b>Cl</b>	5.9	0.65	0.42
<b>K</b>	17.0	1.83	1.07
<b>Ca</b>	157.7	17.95	10.21
<b>Fe</b>	8.8	2.03	0.83
		100.00	100.00

Figure 40 – Quantitative EDAX results for jade dragon reveals oxygen, silicon, calcium aluminum and potassium.



Figure 41 – Guang and several pieces from the interior of the vessel placed on carbon tape.

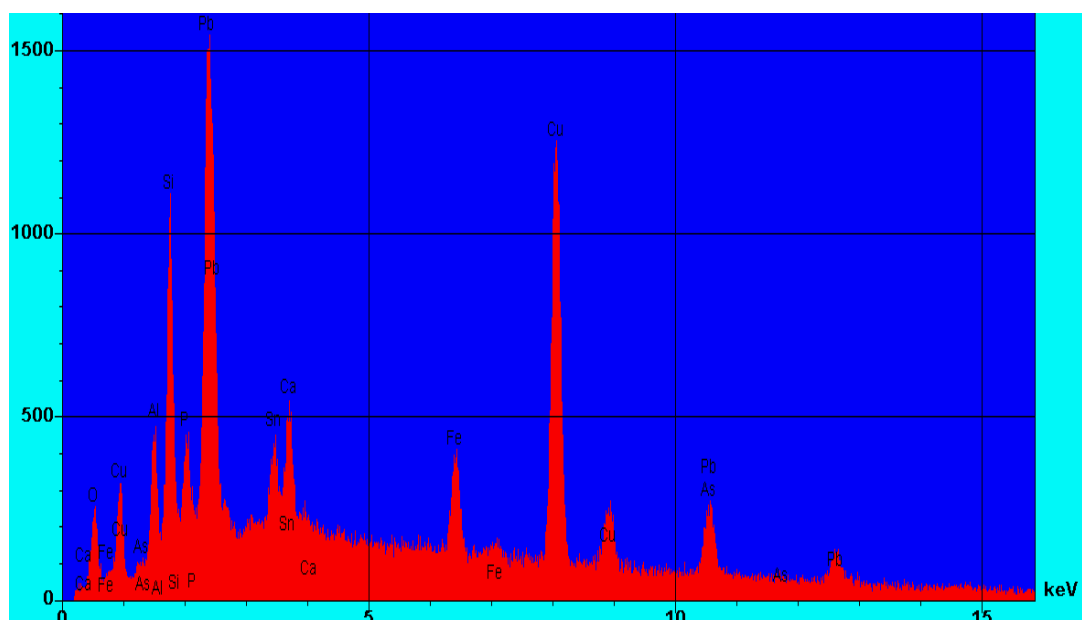


Figure 42 – Guang and its EDAX spectrum showing peak intensities (count rate) for various elements; gold (Au) has the largest peak.

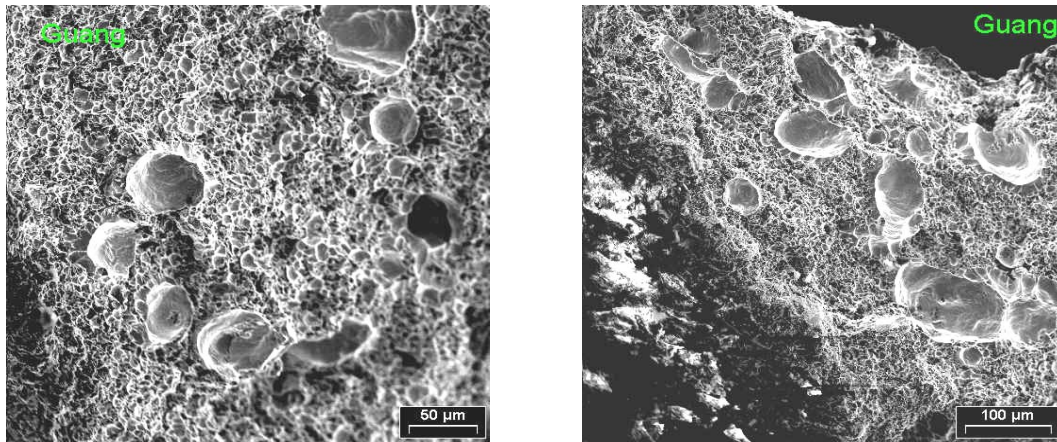


Figure 43 – Gas porosity defects formed during casting of the guang vessel.

Element	Intensity	K ratio	W%	A%
O	19.3	0.02133	8.24	28.39
Al	20.5	0.00739	1.74	3.56
Si	91.8	0.03300	5.64	11.66
P	24.2	0.00940	1.50	2.64
Ca	29.1	0.01626	1.84	2.53
Fe	50.4	0.05434	5.19	5.13
Cu	237.3	0.41576	41.32	35.87
As	14.0	0.03470	0.32	0.26
Sn	35.2	0.04183	5.52	2.56
Pb	175.7	0.21443	28.72	7.44
		0.81353	100.00	100.00

Figure 44 – Quantitative EDAX results for guang showing high atomic percentage of Cu (35.87) and Pb.

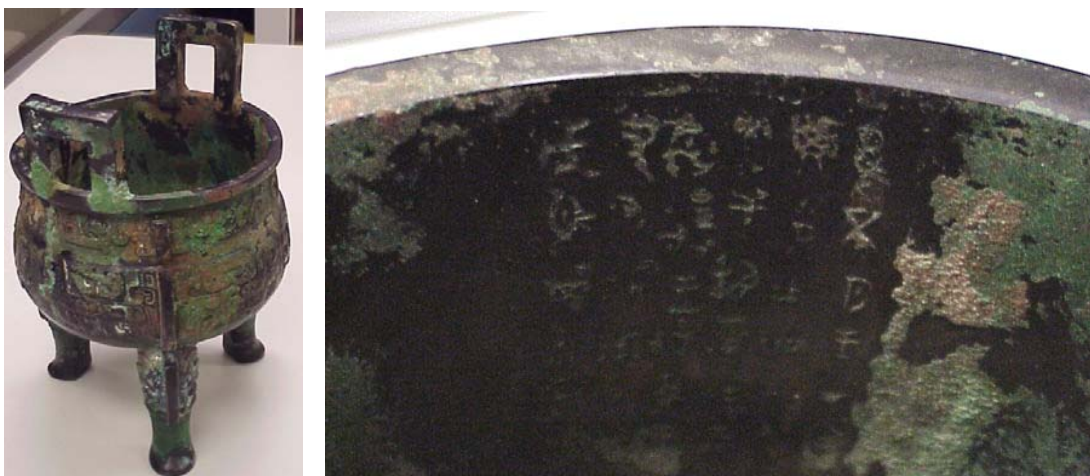


Figure 45 – Bronze ding with interior inscriptions.

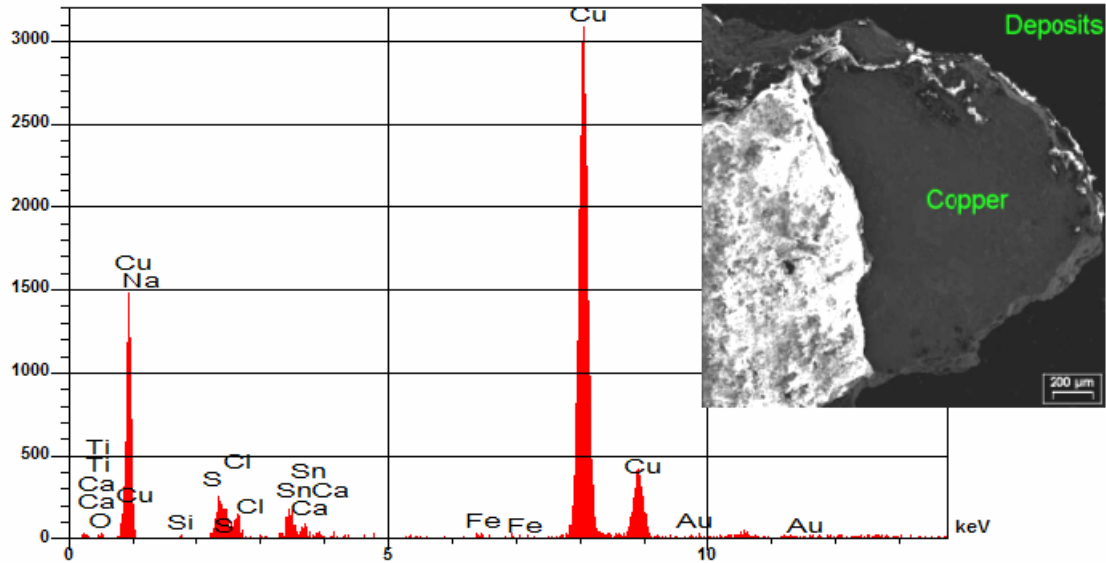


Figure 46 – SEM image of deposit removed from bronze ding and EDAX spectrum showing evidence of copper, chloride and sodium.

Element	Intensity	K ratio	W%
O	1.4	0.43	1.69
Cl	23.5	1.28	2.27
Fe	5.1	0.40	0.45
Cu	599.4	94.38	93.72
Sn	27.8	3.51	1.87
		100.00	100.00

Figure 47 – Quantitative EDAX results for ding deposit showing high atomic percentage of Cu (93.72) and small amounts of iron, chloride, oxygen and tin.

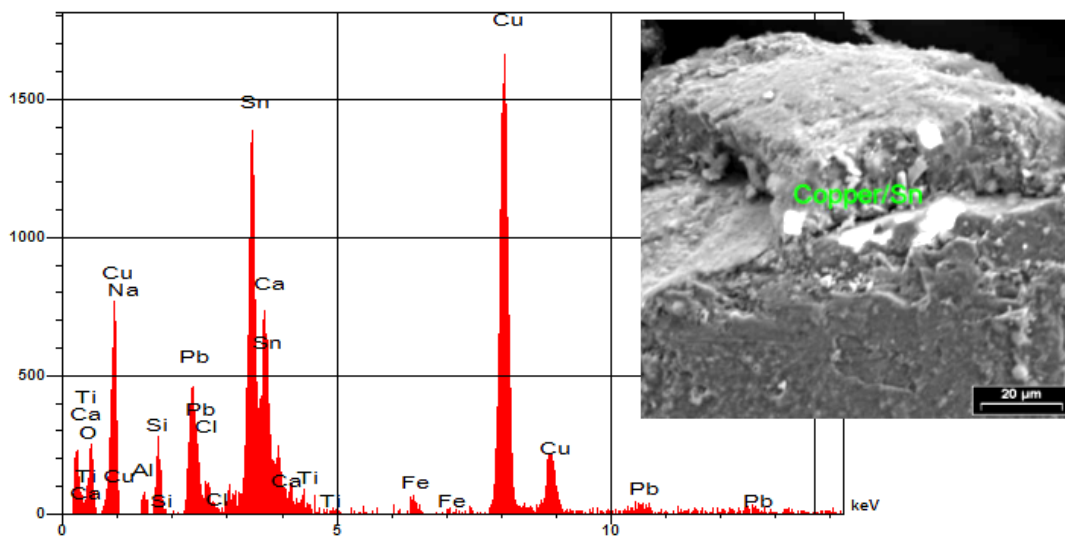


Figure 48 – SEM image of bronze ding and EDAX spectrum showing evidence of copper, tin, chloride, lead and sodium.

Element	Intensity	K ratio	W%
O	36.4	12.80	42.22
Cl	15.8	0.74	1.10
Fe	11.1	0.91	0.86
Cu	355.1	50.19	41.68
Sn	240.1	26.99	12.00
Pb	64.1	8.37	2.13
		100.00	100.00

Figure 49 – Quantitative EDAX results for ding deposit showing predominantly copper and oxygen with small amounts of iron, chloride, lead and tin.

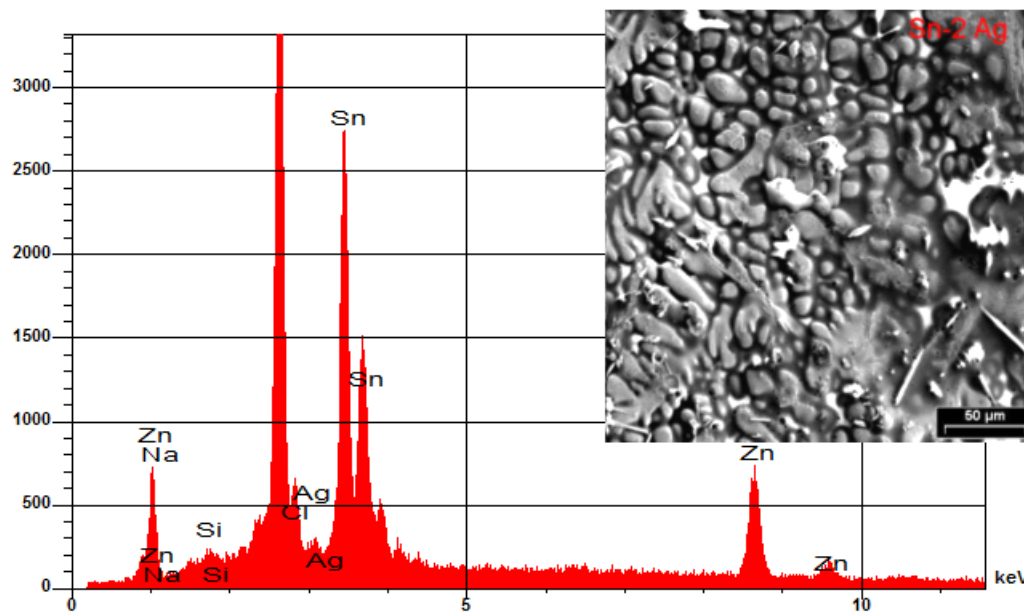


Figure 50 – SEM image of bronze ding at Sn/Ag joint near handle and EDAX spectrum showing evidence of zinc, tin, chloride, lead and sodium.

Element	Intensity	K ratio	W%	A%
Si	1.0	0.00039	0.05	0.11
Cl	647.5	0.24373	27.52	50.19
Zn	127.4	0.22709	22.87	22.62
Ag	11.3	0.01043	1.31	0.79
Sn	394.9	0.39417	48.25	26.28
		0.87557	100.00	100.00

Figure 51 – Quantitative EDAX results for ding deposit show large amounts of chloride zinc and tin.



## Environmental Effects

Over the course of many years (in the case of antiquities, many centuries) bronze may come into contact with water, oxygen, carbon dioxide gas, sulfides, salts and microbes in the soil. Long term chemical and biological reactions, along with foreign elements penetrating into the metal alloy, can easily cause corrosion. Table 2 shows the most common kinds of bronze corrosion and their effect on bronze [15]. It is very useful to know what compounds are present to determine authenticity, as well as the proper course for conservation of the artifact. Removal of the corrosion product may destroy historical information and fine surface features [74]. Objects that have been buried for centuries or millennia may have suffered corrosion effects that are not easily modeled or accurately predicted from the complex list of environmental parameters (moisture content, pH, percent air voids, bulk density, amount of chloride ions, soil type, degree of aeration, calcium content, and many other factors) [74]. Bronze articles exposed to high humidity or buried underground undergo a natural change where they develop a bright coating or patina (Figure 52). The patina serves to protect the metal from further damage and can range in color from red to green to blue [3, 4].



Figure 52 - **a**) Wine container (hu), Eastern Zhou dynasty, Spring and Autumn period (770 – 475 BC), Bronze and copper; Overall height: 15 3/8 in. (39.1 cm) [49]; **b**) Bronze blade, 1000 BC, H: 33.5 cm, W: 15.4 cm [42].

It is not clear how corrosion processes can differ to such a high degree from one burial site to another. Sometimes the variable results are due to the alloy composition; unalloyed copper usually corrodes much more slowly than tin bronze, arsenical copper, or brass alloys. Some smelted copper scraps used for Neolithic ornaments (~4000 BC) showed a thin layer of cuprite and a very thin layer of malachite; this was very negligible corrosion, indicating that the patina had provided the metal protection (a passivation layer) from corrosion [74]. The metal scraps did not suffer thousands of years under aggressive corrosion, as some models would have predicted; the same can not be said for the artifacts seen in Figure 53. During the growth of copper oxide films, oxygen atoms migrate inward and metal atoms move in the opposite direction. As the corrosion process develops and copper ions migrate outward, the cuprite may grow over the initial corrosion layer and build several different layers that can be seen when examined in cross

section (a destructive analysis process). The two most common nonmetallic inclusions in ancient bronzes are copper oxides and copper sulfides [74].

Table 2 - Most common kinds of bronze corrosion and their effect on bronze [15, 74].

Rust Formula	Color	Type
Cupric oxide or tenorite (CuO)	Black	Harmless
Cuprous oxide or cuprite (Cu <sub>2</sub> O)	Ruby Red	
CuS	Dark Blue	
chalcocite (Cu <sub>2</sub> S)	Black	
Cupric carbonate . spertiniite (or malachite) (CuCO <sub>3</sub> . Cu(OH) <sub>2</sub> )	Dark Green	
azurite (2CuCO <sub>3</sub> . Cu(OH) <sub>2</sub> )	Blue	Harmful
Cu <sub>2</sub> Cl <sub>2</sub> . 3Cu(OH) <sub>2</sub>	Green to Black	
Cu <sub>2</sub> Cl <sub>2</sub> . Cu(OH) <sub>2</sub>	Light Green	Harmless
CuSO <sub>4</sub> . 5H <sub>2</sub> O	Blue	
CuSO <sub>4</sub> . 3Cu(OH) <sub>2</sub>	Green	
Cu <sub>2</sub> Cl <sub>2</sub>	White	Harmful
(stannic oxide) SnO <sub>2</sub>	Dirty White	Harmless



Figure 53 - Bronze Seated Lion, Tang dynasty, 618-907 AD, H: 9.2 cm, W: 5.2 cm [43]; severely corroded blade [15].

### Conclusion

It was believed that Chinese civilization developed in the Central Plains (Zhongyuan) area of the Yellow River since this area had been heavily excavated in the 1950s to prepare for a reservoir and the ancient sites of the Yangshao were unearthed. Since this time, major excavation have been undertaken in Sichuan, Shaanxi, Shanxi, Hebei, Shandong, Henan, Chongqing and Hubei, areas thought to be lacking historical context. Chinese history and its contributions to the Bronze Age were profoundly changed with these recent discoveries. In China, the Bronze Age was assumed to have started around

1900 BC, although the earliest dated bronze objects in China are from approximately 3000 BC, similar to the time Greece began using bronze. For comparison, the pre-Columbian civilizations of the Americas had bronze technology in 1000 AD.

The Chinese learned how to smelt copper and tin to make weapons and tools; this required an organized labor force and skilled craftsmen. The high level of workmanship seen in the bronzes in Shang tombs suggests a stratified and well organized society with powerful rulers who were able to mobilize human and material resources to mine, transport and refine the ores, to manufacture the clay models, cores and molds for casting and to run the foundries. Bronze became widespread in the central plain of China in early Shang times. A puzzling aspect about the quality of the Shang bronzes is that they are so impressively large, that there must have been an earlier bronze culture not yet discovered. Furthermore, casting large objects was not easy; it required large crucibles and efficient furnaces. The high temperatures of the Neolithic kilns used to fire pottery were hot enough to melt metals from stone; pottery kilns found near Xi'an could maintain temperatures at 1400 °C as early as 5000 BC. Casting some of the largest objects required coordinated melting in many crucibles similar to a modern factory. But, casting was a more natural progression for the Chinese who had a long history with pottery and jade carving since the Neolithic period. The Europeans were far more reliant on hammering and working the metal into shape during their Bronze Age. For this reason, scholars believe Chinese artisans were able to develop bronze without the influence of other cultures, suggesting an independent Chinese discovery of bronze.

Chinese bronze artifacts at first were very similar to the pottery vessels, but soon evolved into shapes adapted to the specific characteristics of bronze material. Bronze material attributes could acquire countless forms, possess strength and durability, demonstrate brilliant exteriors and musical precision, and serve as religious icons and weapons of war. The number and variety of vessel forms increased, as well as the complexity of decoration and manufacturing techniques. These developments occurred alongside improvements in casting technology; advances that included process planning, extracting, refining, bronze casting and experimentation with vessel form and decoration. The ancient Chinese developed a most unusual casting method called the piece mold process where surface decoration could be made by carving into the mold or into the model. Bronze technology reached a peak around 770 to 476 BC and combined a specialized metal casting method called the lost wax technique with the piece mold process. There is great appreciation for the progression of metallurgical processing techniques that evolved over thousands of years. Late Shang bronze art is highly regarded and considered one of the most outstanding achievements of ancient Chinese civilization. In the Republic of China today, the beauty of traditional bronze art is still a central theme in modern architecture.

### **Future Work**

Countless hours were spent researching ancient China, and in some cases we have only skimmed the surface; new excavations were revealed in 2005 adding to the resource information. While in Beijing attending an archaeometry conference, we discovered further areas of investigation and visited the museums where some of the artifacts are

maintained. There are many fascinating and relevant areas that we would like to pursue: 1) collaboration with Los Angeles County Museum of Art (LACMA); 2) continued metallurgical investigations to compare the piece mold technique with the lost wax method; 3) metallurgical study of Chinese coins; 4) collaboration with the Institute of Historical Metallurgy & Materials in Beijing; and 5) methods for authenticating an artifact.

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