THE RELEVANCE OF CONTEMPORARY BRONZE CASTING IN UBON, THAILAND FOR UNDERSTANDING THE ARCHAEOLOGICAL RECORD OF THE BRONZE AGE IN PENINSULAR SOUTHEAST ASIA

A Thesis

by

DANIEL EUGENE EVERLY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

December 2004

Major Subject: Anthropology

THE RELEVANCE OF CONTEMPORARY BRONZE CASTING IN UBON, THAILAND FOR UNDERSTANDING THE ARCHAEOLOGICAL RECORD OF THE BRONZE AGE IN PENINSULAR SOUTHEAST ASIA

A Thesis

by

DANIEL EUGENE EVERLY

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Approved as to style and content by:

D. Bruce Dickson (Chair of Committee)	Norbert Dannhaeuser (Member)
Edward Runge (Member)	David Carlson (Head of Department)

December 2004

Major Subject: Anthropology

ABSTRACT

The Relevance of Contemporary Bronze Casting in Ubon, Thailand for Understanding
the Archaeological Record of the Bronze Age in Peninsular Southeast Asia.
(December 2004)

Daniel Eugene Everly, B.S., University of Houston;
M.A., University of Houston at Clear Lake
Chair of Advisory Committee: Dr. D. Bruce Dickson

A direct historical approach is used in this thesis to document the lost wax casting technique as currently practiced by indigenous metallurgists in northeastern Thailand. The smiths observed at Ban Pba Ao, Ubon Ratchathani Province are the last practicing members of a bronze working tradition that has been in continuous operation at the village for two centuries. An account of the processes used to create bronze bells is provided. Of particular significance is the fact that the yard in which casting activities are performed did not receive clean up operations following the bells production. As a result, hearths, bowl furnaces, crucibles and fragments of clay moulds are left scattered about the yard. These materials accumulating in one location would eventually create a mound of cultural debris. The discarded materials from the lost wax casting process as practiced at Ban Pba Ao provide considerable insight into what might be found in the stratigraphy of Peninsular Southeast Asian prehistoric sites that were involved in the production of bronze objects. The study concludes that attention needs to be paid to the stratigraphic sequences from which bronze artifacts are extracted, rather than relying on

the artifacts to determine the type of process used in their manufacture.

DEDICATION

To my family, who taught me how to love.

TABLE OF CONTENTS

Page

CHAPTER Page

CHAPTER Page

Page

CHAPTER I

INTRODUCTION

This thesis investigates the production of bronze objects in northeastern Thailand. A detailed step by step account of the lost wax casting process as currently practiced by smiths in the Ubon Ratchathani Province is provided. The types of residues and discarded materials produced during this particular manufacturing process are reviewed to help determine how Peninsular Southeast Asia's archaeological record might best be investigated to provide evidence for the particular casting techniques that were used to manufacture bronze objects during the prehistoric period.

In northeastern Thailand is the Khorat Plateau, called Isaan by locals but referred to as the "poor house" by those in the country's lush central valley. The region receives much less rainfall due to being surrounded by mountains and as a result its production of the staple crop rice is considerably less than that of the central valley. Virtually ignored until the late eighteenth century by Thailand's political system, the region's people have very strong cultural affinities to Laos, its neighbor to the east. Isaan's largest urban center, Ubon Ratchathani with nearly a million residents, appears at first glance to be just a smaller Bangkok due to its congested highways and long rows of four story shop houses. Although Thai is the primary language spoken, Isaan, Khmer and Vietnamese can be heard in any given shop one happens into. Unlike Bangkok, in which many of the

---

This thesis follows the style and format of *American Antiquity*.

businesses cater to the tourist trade, shops in Ubon are engaged almost exclusively in the business of supplying the needs of the local rice farming industry. The largest number of foreign visitors to Ubon occurs in July during the Candle Festival. For an entire week large candle floats are paraded through the city streets to graphically demonstrate the key Buddhist mantra that “everything is fleeting,” as evidenced by the rapid disintegration of the exquisitely crafted wax designs by the intense heat of the summer sun.

In contrast to this lesson in impermanence, a visit to the Ubon Ratchathani Provincial Museum located adjacent to Ubon’s central plaza provides a glimpse into the depth of the human experience in the local region. On display is an extensive collection of bronze artifacts from the Ban Kan Luang site located on the northern perimeter of the city. The site, excavated by the Thai Fine Arts Department in 1990, yielded large ceramic burial urns which contained grave goods ranging from bronze jewelry, weapons and utilitarian wares to pottery manufacturing tools and ubiquitous rice grains. Dated to the last half of the first millennium B.C., the bronze artifacts in particular are so intricately designed that their manufacture was clearly the work of nothing less than expert craftsmen. It was a visit to this museum in the summer of 2002 that sparked the author’s
imagination to seek a greater understanding of the origins of the culture that produced such an enduring legacy for the people of Ubon.

When discussing the museum collection with relatives living in Ubon, I was informed that in the nearby village of Ban Pba Ao, smiths were still practicing traditional methods of producing bronze items. A trip to this rural village introduced me to an elderly gentleman, Khun Phryop, who had been a bronze smith there for over sixty years. His family continued to use the lost wax process to manufacture bronze items ranging from animal figurines to betel sets to bells. I was informed that the shop had suspended its work for the next several months as the rainy season was about to begin which precluded performance of many of the steps involved in the process. After selling me a betel set and several bells, Khun Phryop invited me to come back during the next dry season to see just exactly how bronze items were produced by the lost wax process. A chance to conduct an ethnological study related to the production of bronze items presented an excellent opportunity to gain direct insight into the details of this fascinating craft.

After obtaining the necessary permits from the Texas A&M University's Institutional Review Board, the Thai Fine Arts Department and the National Research Council of Thailand to conduct the ethnological study of the Ban Pba Ao bronze smiths and to photograph the Ban Kan Luang artifacts, the author and his Thai research assistant returned to Ubon to complete the study in June 2003. The year spent reviewing the literature concerning metallurgical practices revealed that considerably much more is known about the Metal Ages of Southwestern Asia than is known for Thailand, the Southeast Asian Peninsula, and Eastern Asia. While the archaeological record reveals that East Asian people benefited in many ways from the introduction of metal, very little is known about the methods by which metallic objects were manufactured.

Using the experimental archaeological model as a guide, the author's detailed descriptions and photography of the lost wax process as practiced by the smiths at Ban Pba Ao provides a record of what is involved in this particular manufacturing technique. Several definitive insights into the types of residues and discarded materials that should be found in the archaeological record of a site which may have used this same casting method during prehistory have been revealed. Although the Ban Pba Ao smiths attempted to use traditional practices as much as possible to produce bronze objects by the lost wax casting method, some use of modern mechanization did occur making the account given of this process less than a totally accurate description of the methods that might have actually been used in antiquity. However, as it from the waste products rather than from the actual bronze objects that the greatest insights have been gleamed, the effects of the smith's use of mechanization on creating these wastes should be minimal.

While this thesis uses the direct historical approach to document the current smithing practices in one small village on the Southeast Asian Peninsula, sufficiently deep background material is also provided in this paper to adequately document the relevance of these activities to the region's archaeological record. The chapter on metallurgical processes is intended to provide the reader with a broad overview of humankind's manipulation of copper metals, which began nearly nine thousand years ago in Southwestern Asia. The chapter on the East Asian Bronze Age is intended to inform the reader of the sudden appearance of a full Bronze Age in this region during the second millennium B.C., without the long and tedious period of experimentation that typified Southwestern Asian smiths. This chapter also is intended to demonstrate that the use of bronze moved in a western direction from East Asia to Southeast Asia during the second millennium B.C. The chapter on Peninsular Southeast Asia provides an account of the region’s physical characteristics, history and late prehistory. There are two chapters concerning the production of bronze bells by the smiths at Ban Pba Ao. The first provides a day to day account of the researchers contact with the smiths. The second provides a detailed account of the actual steps involved in manufacturing bronze objects by the lost wax casting process. The final chapter reviews the residues and discarded waste products associated with the lost wax casting process in an effort to identify the types of artifacts that should appear in the archaeological record of a prehistoric site if this particular manufacturing technique had been used to produce bronze objects.

CHAPTER II

METALLURGICAL PROCESSES

Humankind’s manipulation of copper began in Southwestern Asia in the seventh millennium B.C. with the hammering of naturally occurring nodules of extremely high purity into items of personal adornment and simple blade tools. During the following three millennia of the Chalcolithic period, humans discovered the tremendous benefits of applying heat to copper. Heating native copper increased the metal’s strength and hardness while melting copper ores in crucibles increased the availability of materials. By the fourth millennium B.C., alloying copper with arsenic allowed humans to produce the first bronze items thereby ushering in the Early Bronze Age. This was a period of much experimentation as humans faced numerous challenges in their attempt to release copper from the increasingly complex grades of ore being mined from deeper within the locally available mineral deposits. Metallurgical experiments by modern investigators with replicas of various smelting furnaces have provided some insight into the range of difficulties the Early Bronze Age smiths had encountered. By the middle of the second millennium B.C., the task of efficiently separating copper from the other impurities in the ores was accomplished with humankind’s development of high temperature furnaces. With the significant increase in availability of almost pure copper materials that resulted from this accomplishment, Southwestern Asia entered the Late Bronze Age.

Elemental Copper

Copper has the distinction of belonging to the class of noble metals. This assignment is due to its mechanical property of being capable of producing a bright, reflective surface when polished. Copper, like the noble metals gold, silver and platinum, owes this quality to the arrangements of its atoms into what is called a face centered cubic lattice. In addition to an atom at each of the eight corners in the cubic structure, there is also an atom in the center of each of the six faces, making a total of 14 atoms in the lattice (Chandler 1998:12). Of all the possible lattice structures, this arrangement results in the atoms being packed the closest. Purist of all the noble metals at levels approaching 99.9 percent, copper occurs naturally in agglomerated nodules weighing up to several hundred kilograms. Unlike its classmates, however, copper is corrosive when exposed to moisture and will loose its luster over time. The uniform corrosion of copper occurs as a result of an electrochemical reaction in which microscopic galvanic cells form on the metal's outer surface. Stress corrosion cracks eventually propagate through the lattice structure causing further decomposition of the copper whenever prolonged exposure to ammonia solutions, amines and water occurs such as during geologic time.

Copper Deposits

Copper ranks low among the elements in the earth's crust comprising only about 0.010 percent of the lithosphere (Nutt 1968:183). It is found in the shear zones associated with the repeated folding and faulting during plate subduction occurring at all the continental boundaries and in many of the larger island arcs. Copper deposits are therefore often found embedded in metamorphic rocks ranging from the softer schists to harder quartzites. "The primary metal sulphide ore veins are converted by the action of oxygen and water into metal oxides, carbonates and sulphate. These are concentrated immediately below the ground water level and also at the top gossan zone" (Bateman as cited by Hegde and Ericson 1985:62).

The surface gossan zone reaching depths of 3-4 meters, also known as the "iron hat" due to it being primarily made up of iron oxides, is where the purplish brown native copper nodules of very high purity are found. Also within the surface zone is where the cuprous oxide ores, containing the ruby red colored mineral cuprite, is found. Of all the copper ores, cuprite contains a copper content most similar to native copper with a metal content of 88.8 percent (Brandes 1983:7-3). The carbonate ores, containing the bright blue colored azurite and green colored malachite minerals, are found in a layer below the gossan zone and above the ground water level. These minerals contain just 2-3 percent copper due to the translocation of this element downward by the effects of gravity and water action. Below these two zones lies the enriched sulphide ores with a copper content ranging from 25-30 percent and sulphur content of up to 60 percent. These include the sparkling gray chalcocite and covellite minerals also known as "Fahlzer" ores. Although present in all zones, it is in this enriched zone that appreciable concentrations of the arsenic and antimony minerals are located (Tylecote 1992:10). Arsenic ores are more commonly encountered in the enriched zone than are those containing antimony. The green arsenate, Olivenite, similar in appearance to malachite and common in the enriched zone becomes extremely rare in the zone below. The lowest zone consists of mixed copper/iron sulphides along with iron pyrites on which the deposit was originally based (Charles 1985:23). These mixed sulphides include purple colored bornite and yellow colored chalcopyrite with a copper content ranging from just

2-4 percent. It should be noted, however, that not all copper deposits are primary in nature as some are secondary alluvial deposits consisting of disseminated oxide minerals with some concentration back to nodules.

Native Copper

Humankind’s ritualistic use of the iron oxide, hematite, is well documented in the archaeological record since the Middle Paleolithic. Initial human encounters with native copper were in this author’s opinion a likely outcome of hematite collection on the "iron hat." Striking the dull corroded surface of a native copper nodule with a hammerstone would have produced a bright scar capable of reflecting sunlight back from its surface. This aesthetic property would not have gone unnoticed by the human eye and would have served to ensure its collection. The cold hammering of native copper was found to have the benefit of hardening a material that prior to such treatment seemed to have very little strength. However, native copper cannot be extensively worked without causing cracks to develop. Cold working causes plastic deformation of the copper's grain structure resulting in a reduction in their size. Continued cold working results in the application of sustained stress beyond the material's elastic limit thereby causing cracks to propagate. Intermittent annealing restores grain structure to its original condition to help prevent these undesirable effects of cold working (Chandler 1998:23-24). Annealing involves heating the worked edge of a copper item for a short time in an open fire. The appearance of these systematic manipulations of copper in the human record mark the beginning of the Chalcolithic Period. The oldest native copper artifacts known are an awl from Tel Magzallia in Iraq that was cold worked to a hardness of 106 HV and a small bead from Ali Kosh in Iran made from a rolled up copper sheet of about 0.4 mm thickness with a hardness of 109 HV, both dated to the seventh millennium B.C. (Tylecote 1992:2). The fact that these items are associated with weaving and personal adornment suggests that the smiths that made them could have been female rather than male.

Initial Copper Ore Use

Mining of copper ores became necessary once the majority of the native copper nodules from the surface had been collected. The majority of the oxide ores could be fairly easily gouged from the top several meters of a mineral outcrop. To facilitate removal of the deeper carbonate ores from their veins, rock joints could be expanded with the addition of heat provided from bonfires. Although a bonfire does not produce the heat necessary to melt copper, the roasting of ores was found to concentrate the ore's copper content, a highly desirable outcome for carbonate ores with their low copper content.

Roasting azurite and malachite drives off the moisture and breaks down the carbonates thereby completing the decomposition process already started by exposure to the air and water. The combustibles naturally present in the ore burn easily and reduce the residual oxides and sulphides, forming globules of metal which grow in varying degrees according to the duration of the roasting. This first step in the reduction of copper ores could be achieved in a hearth furnace burning charcoal or dry wood to produce the 700 plus degrees Centigrade temperature required to release the copper metal (Charles 1985: 22). The operation needed to be repeated up to sixteen times to increase the richness of the matte to obtain a 20 percent concentration of copper (Marechal 1985:30). This is necessary due to the fact that when roasted, the copper in the ores becomes concentrated into small buttons or prills less than a millimeter in diameter. Repeated roasting results in a greater agglomeration of these prills thereby making their separation from the gangue (waste) materials much easier. This step was accomplished by crushing the roasted ore containing the matte (agglomerated prills) which could then be further concentrating through gravity separation techniques.

Separators found near mines in the Aravalli Hills in northwestern India consisted of a smooth, gently inclined rock surface, neatly marked with rows of round shallow pits, 3-4 cm in diameter and 3-4 cm in depth. The finely crushed ore was allowed to slowly flow down the inclined plane and by repeating this process, much of the gangue was effectively separated from the ore (Hegde and Ericson 1985:63). The principle behind this operation involves the fact that ore particles containing copper are denser than those ore particles without. This results in the copper containing ores dropping down into the shallow pits while the lighter materials simply continue to roll down the inclined surface.

Crucible Furnaces

Working with concentrated copper ore, the smiths discovered that placement in a crucible made of clay helped to contain the charge within a confined area rather than simply allowing it to run down into cracks in the hearth furnace. In an experiment conducted in 1940 (Coghlan as cited by Tylecote and Merkel 1985:4), Coghlan demonstrated that while an open fire alone was unsuitable for smelting copper, the use of a covered crucible within a charcoal fire could produce small beads of copper from crushed malachite ore. This led Coghlan to the conclusion that smelting may have been first discovered in ceramic kilns.

In a series of experiments conducted in 1975, Friede and Smith (as cited by Tylecote and Merkel 1985:5-6), roasted malachite ore with a copper content of 17.5 percent for three hours at temperatures ranging from 800 to 1,000 degrees C in a furnace 18 cm in diameter by 42 cm in height that was made of firebrick. In each experiment conducted with this furnace only a small quantity of reduced copper, in the form of tiny globules and thin irregular shaped copper layers coating the surface of the slag were obtained. The authors then built a shallow clay lined pit of about 20 cm diameter, surrounded it with stones, placed four stones into the center of this pit, and filled the pit with charcoal. A small clay crucible of 8 cm diameter containing the copper prills collected from the earlier experiments along with some dry leaves was placed on the four stones located in the middle of the pit, covered with a ceramic lid and the charcoal ignited. Additional charcoal fuel was added to envelop the crucible into which two tuyeres (blow pipes) were positioned so as to supply air onto the sides of the crucible. A temperature of 1,100 to 1,200 degrees C was maintained for about thirty minutes. A chemical analysis of the product in the crucible revealed it to contain 4.4 percent iron, 0.02 percent nickel, 0.008 percent zinc and less than 10 parts per million tin, lead, antimony, bismuth, and arsenic; the rest was copper.

In an undated experiment using a crucible 10 cm in diameter and 3 cm in depth, Zwicker and his colleagues (Zwicker et al. 1985:104) roasted a concentrated copper sulphide ore containing 29 percent copper, 27 percent iron, 31 percent sulphur, 5 percent silica, 0.15 percent zinc and 0.02 percent arsenic under a 50 cm heap of charcoal to a temperature of 800 degrees C. The product from this roasting was then smelted in the crucible to metallic copper at 1,100 degrees C by using between three and six tuyeres to produce the needed blast. The recovery of copper was a little more than 50 percent mixed with slag material. When malachite ore was reduced through the same process the recovery was more than 90 percent and no slag was produced.

These experiments indicate that intensely heating pre-roasted malachite ore in a crucible under charcoal drafted by an air blast produced through multiple tuyeres could reliably produce the 1,084 degrees C temperature needed to agglomerate copper to levels similar to native copper. However, the appearance of impurities ranging from 5-10 percent in the products achieved from smelting malachite ores would have indubitably presented considerable challenges to the smiths as they worked these materials into final form. Striking an impurity, such as an iron granule, during cold hammering copper material would have created a discontinuity in the surface being prepared and thus a lesser quality product resulted. This exchange of impurities during smelting, known as metathesis (Nutt 1968:6), would become a progressively more challenging problem as ores, which had experienced even less natural weathering than malachite began to be utilized. The Zwicker experiment clearly indicates the decline in efficiency of recovering copper products when sulphide ores rather than malachite ores were smelted in crucible furnaces. This finding indicates that additional processing would be required to effectively separate the copper from the gangue once the use of sulphide ores began to predominate. The development of the bowl or hole-in-the-ground furnace along with the use of fluxing agents to sequester the growing iron content provided the technological improvements needed to more effectively reduce the sulphide ores.

Arsenic-Copper Alloys

As the use of arsenic-copper alloys to produce arsenic-bronze occurs as a separate and distinct phase of metallurgical development at the end of the Chalcolithic and the beginning of the Bronze Age, this topic will be discussed before addressing the smelting of sulphide ores, which dominates the Early Bronze Age. “There are advantages over pure copper in terms of castings where the arsenic acts as a de-oxidant. Up to 7 percent arsenic material can be work-hardened very substantially by cold hammering without cracking to strengths equivalent to tin-bronze. Presumably the first recognition of the new material came when green stones, of similar but not identical appearance to malachite, initially collected as charge gave better material “(Charles 1985:25). As mentioned previously, the green arsenate Olivenite becomes common in the enriched zone containing the sulphide ores. Thus, arsenic-bronze production and the use of bowl furnaces to smelt sulphide ores co-occur due to the location of arsenates and sulphide ores in the same level of a copper bearing deposit. The only difference that could be easily used to detect arsenic in a charge would be the peculiar garlic smell associated with its roasting. The smell is even detectable when hammering arsenic ores and eventually the prospectors could intentionally select arsenates by this method rather than the smith having to rely just on chance inclusion in the charge. “The remarkable fact is that 2 percent of arsenic can confer upon copper a beautiful golden color. Tensile strength is already increased at 0.1 to 0.5 percent arsenic" (Needham 1974:223). The appearance of the oldest known arsenic-bronze artifacts, a spatula, awl and chisel from Tepe Yahya in Iran dated to 3800 B.C., mark the end of the Chalcolithic Period in Southwest Asia.

By the time arsenic was being alloyed to copper, melting in crucibles had become well established and the possibility of re-melting metallic copper with surface additions of concentrated minerals under a charcoal cover had become easily achievable. Arsenic could have been added from arsenic/sulphide minerals or from a high arsenious oxide product directly to metallic copper. The possible mechanism can be envisioned as the formation of a surface speiss (metallic arsenides) following the addition of the arsenic material to the molten copper with its subsequent diffusion into the copper due to the miscibility (blending) qualities of the two materials. "Once the arsenates were exhausted in copper deposits, the addition of arsenic from such materials as enargate, tennantite and arsenophyrite would involve substantial losses of arsenic in the roasting stage of heating, and the volatility of arsenious oxide would make control of arsenic content difficult" (Charles 1985:26). Charles believed that extreme health hazards including nerve damage and death were the cause for the short-lived use of arsenic as an alloying agent.

Sulphide Ores and Fluxing Agents

The search for a safer alloying agent than the volatile arsenic minerals together with the growing problems being encountered with use of the sulphide ores resulted in the occurrence of a marked recession in production at the beginning of the Early Bronze

Age while the industry set about the task of retooling itself. After the depletion of the nearly pure native copper and high-grade oxide ores, all artifacts began to contain more impurities due to the difficulty of separating copper product from waste slag material. ”Crucible slags result from the reaction between the alkali in the fuel ash and silicates from the fabric of the crucible, and usually carry large amounts of entrapped copper. They would be viscous and separation would be poor, thus giving a large amount of residual copper. A more efficient way of getting slag/metal separation was to add a flux, either iron oxide or manganese oxide, and thus turn the high silica content into a Fe or Mn silicate” (Tylecote 1992:7). However, fluxing slag did not actually cause separation of this waste material from the copper product; rather it only caused the slag to be less viscous in its Fe silicate form (fayalite).

With utilization of the self-fluxing sulphide ores, the marked increase in the amount of slag produced was directly proportional to the amount of iron in the ore. Now instead of adding iron to flux the silica in the slag material, silica in the form of sand needed to be added to flux the iron to produce the desired less viscous slag. Without actual separation of this slag from the copper product, the problem of metathesis continued to result in iron and sulphur impurities becoming attached to the surfaces of the embedded copper prills. Unlike the alloy with arsenic, which produced an improved product, the alloy of copper and iron produced an inferior product due to the immiscibility (lack of blending) of these two materials.

Separation of the slag from the copper product could not be achieved in the small bowl furnaces due to their inability to produce the 1,170 degrees C needed to melt the fayalite slag. Attempts to remedy the problem by enlarging the size of bowl furnaces to accommodate the increased volume of fayalite slag material being produced caused the smiths to explore methods of increasing the air draft sufficiently to smelt larger charges. Only after a temperature of 1,200 degrees C was eventually achieved and maintained could the immiscibility qualities of copper and fayalite slag be taken advantage of. At the temperature of 1,200 degrees C, fayalite slag melts and becomes liquefied. Thus, molten copper, with its higher density of 8.89, is now able to drop threw the molten slag, due to its lower density of 4, and settle into the furnace bottom to form an ingot.

Bowl Furnaces

The following sets of experiments provide invaluable insights into the variety of problems encountered and their possible solutions as bowl furnaces began to be utilized to smelt the more complex ores.

A series of thirteen copper smelting experiments were conducted by Tylecote and Boydell in 1978 (as cited by Tylecote and Merkel 1985:6-7). The investigators built a bowl furnace of firebrick measuring 22 cm in diameter and 30 cm in height using archaeological evidence from Timna Site 39 in Israel. A column of regular brick was built upon a rectangular brick base into which the furnace of the above-specified dimensions was built inside, separated from each other by a layer of sand. The furnace was lined with a mixture of clay, sand and charcoal dust. A single tuyere, measuring 1.9 cm in diameter was placed at an incline through the furnace wall at a height that varied between 16 and 18 cm above the furnace bottom. In the second experiment, the tuyere was placed vertically into the furnace to a depth 12 cm above the hearth.

The first five experiments used copper oxide or copper metal plus metatite flux, at various ratios. Airflows from 100 to150 liters/minute were tested. Preheat times were about one and a half hours. Post heat charcoal additions after the last ore charge varied up to two and a half hours. A temperature profile taken during the third experiment showed that the bottom temperatures in the furnace were too low to melt the slag. At best the smelting products were copper prills mixed with slag. Recovery of input copper ranged from 42 percent to 94.5 percent.

A second set of eight experiments were conducted using crushed nodular ore from Mt. Timna with fragments measuring less than 4 mm each. A 1:2 ratio of ore to hematite flux was found to be optimal. In experiment B9 no hematite was added to demonstrate that the nodular ore was not self-fluxing and in this case the copper could not be separated from the slag. A 1:2 ratio of charcoal fuel to ore/slag mixture was also found to be optimal. A 1:3 fuel to ore/slag mixture caused the tuyere to become blocked with slag. The subsequent decrease in temperature resulted in poor separation of molten slag and copper. Smelting products from these experiments were copper prills containing impurities of iron and sulphur with iron being the more plentiful of the two.

Eight refining experiments were conducted on the impure copper prills. Due to the differences in density and the immiscibility between copper and iron, the iron could be recovered from the top of the copper under laboratory conditions, which permitted higher temperatures to be used to melt the iron. However, under the normal smelting conditions in their small bowl furnace, the iron content formed ferrous oxide, which in turn formed fayalite slag with the charcoal ash and clay from the fabric of the furnace lining. This set of experiments indicates some of the difficulties encountered in the use of bowl furnaces to smelt ores with an iron based fluxing agent. They indicate that additional technologies needed to be developed that could more easily separate the copper product from the increasing amounts of slag waste being generated during smelting of the self-fluxing sulphide ores. This technological advancement involved gaining behavioral control of these self-fluxing iron rich sulphide ores through refinements in the furnace design.

A series of seventeen experiments conducted in 1976 by Ghanznavi used a bowl furnace of firebrick measuring 23 cm in diameter and 30 cm in height (Ghanznavi as cited by Tylecote and Merkel 1985:7). A single inclined tuyere of unspecified dimensions positioned 11 cm above the furnace bottom was used to provide a blast of 150 liters per minute in the first four experiments. Oxide ores were used in only experiments 2 and 3. Copper prills were reported at efficiencies of 69 to 80.2 percent.

An additional tuyere was placed at the top of the furnace in the twelve subsequent experiments, which used sulphide ores. This additional charge was introduced to increase the burning of carbon monoxide in the exhaust gases. The reported benefit of the second tuyere that increased airflow and temperature was an improvement in copper and slag liquidation. It increased the temperature distribution considerably and allowed formation of something resembling an ingot rather than the usual copper prills embedded in slag. “At temperatures above 700 degrees C, the carbon monoxide to carbon dioxide ratio increases rapidly in equilibrium with carbon, giving efficient gaseous reduction” (Charles 1985:22). “It would, in fact, be necessary to maintain a suitably mildly reducing atmosphere in order to not produce too much metallic iron in association with copper" (Charles 1985:25).

These findings indicate that it was the increased presence of a carbon monoxide atmosphere, maintained at very specific levels that proved to be the ultimate ingredient required to achieve the complete reduction of the sulphide ores to metallic copper. Discovery of the need to provide an adequate draft to create this optimal reducing environment triggered the resurgence in production of metallic objects noted in the Late Bronze Age.

Archaeology of Furnace Evolution

Rothenberg's report (Rothenberg 1985:124-129) on the excavations at Mt. Timna in Israel provides a clear picture of the evolution in furnace design required to accomplish the task of effectively separating fayalite slag from the copper product. In his descriptions of the archaeology at three sites at Timna, the author reveals the innovative steps taken by the smiths to gain behavioral control of the iron rich sulphide ores. The description of Timna site 39 indicates the limitations terminal Chalcolithic smiths were experiencing with their small hole-in-the-ground furnaces. The archaeology of Timna site 30 indicates the major advancement in pyro-technology that had been achieved by the middle of the second millennium B.C. with the production of the first true ingots within the larger bowl furnaces. Within just a few centuries of this accomplishment, evidence from Timna Site 2 reveals that considerable sophistication in furnace construction, involving the use of heat retaining walls to create the first shaft furnaces, had been developed to ensure the proper maintenance of temperatures and atmospheric conditions required to efficiently separate the metallic copper product from the slag waste.

Terminal Chalcolithic Furnaces

A copper smelting furnace was excavated at Timna Site 39 dated to the late Chalcolithic Period (second half of the fourth millennium B.C.) by pottery and stone tools. It was a hole-in-the-ground, bowl shaped smelting hearth with a low superstructure of small rocks around its rim. No lining was found in situ inside the furnace. The inner surface diameter was about 45 cm, and its depth 45-50 cm. The furnace bottom was solid bedrock. No tuyeres were found at the site (Rothenberg 1985:137).

Small crushed pieces of rather viscous slag were found dispersed around the furnace and over much of the hillside. Among the dispersed slag were pieces of slagged, hard-burned soil lumps and also small slagged rocks, which appeared to be fragments of a smelting hearth. The appearance of the furnace remains and slag indicate that the whole of the in-ground furnace contents was raked out at the end of the smelting operation, removing part of the slagged furnace walls. This indicates that the dimensions of the excavated furnace were larger than the hole-in-the-ground smelting hearth at the time of its actual operation. No slagged furnace lining was found at the site and the slagged lumps of very sandy soil, found near the furnace and among the slag, were apparently the sintered parts of the unlined sandy sides of the hole-in-the-ground furnace raked out together with the slag. These findings indicate that separation of slag from the copper product had not been accomplished by the end of the Chalcolithic Period.

Slag-Tapping Furnaces

At Timna Site 30 copper smelting operations dated to the late fourteenth century B.C. were excavated. The smelting installation consisted of a small, clay-lined bowl furnace standing on the edge of a stone paved working floor. Most of the installations were contained by a roughly built stone fence, which served as a retaining wall for the ever growing slag heaps around the smelter. The furnace at Locus 50 was built of stone and sand, lined with a layer of clay mortar, its slightly concave bottom had a diameter of about 40 cm and it had tapering sides (Rothenberg 1985: 137 and 143). Its exact height is unknown but the height of the preserved walls around it suggest that it was about 50 cm high. A similar furnace at Timna Site 185 was of a similar shape and size, however there were two layers of clay lining indicating refitting of the hearth after its first operation.

Several additional fragmentary copper smelting furnaces were found in the smelting camps of the Timna Valley. Whenever furnace walls were found in situ, their lowermost parts near the bottom were never slagged. The same applied to the furnace bottom whose typical appearance would be that of a rather eroded, slightly concave or flat surface covered by a very fine, light-gray colored, dusty layer of burned clay, often mixed with very fine charcoal dust. However, contrary to the furnace bottom, the lining of the lower part of the furnace wall was usually missing, apparently forcefully removed together with the contents of the smelting hearth. Although parts of furnace walls were found in situ in a number of furnaces, there was not enough evidence found for the construction of the top portion or to identify the height of the smelting hearth.

Although no tuyeres were found in situ in any of the excavated furnaces, a very large number of small hemispherical clay tuyeres, 6-7.5 cm wide, 4-7 cm long with a central aperture of 2 cm were found on the working floors and slag heaps belonging stratigraphically to the Late Bronze Age (Rothenberg 1985:144). All tuyeres found were of uniform shape, but the amount of slag material on their surfaces indicated different positions in the furnace walls. Most of the tuyeres protruded into the smelting hearth at an angle of 25 to 30 degrees to the horizontal, but there were others which must have protruded into the furnace horizontally. Horizontal tuyeres could have been introduced into the furnace only through the furnace front. Vertically inclined tuyeres were also found and these could have been located anywhere in the upper part of the furnace with its outer end most likely at the level of the working surface well above ground level.

The slag produced by these furnaces was basically of two types and as both were always found together, it seems that they were produced by one and the same smelting process. The first was a solid black plate slag, 2-3 cm thick, which was formed by tapping the slag onto a flat surface outside the furnace and then breaking it up into small pieces, probably to extract any entrapped copper. Second was a non-tapped furnace slag of a rather viscous appearance, full of gas holes, charcoal, semi molten gangue and some copper prills (Rothenberg 1985:145). This slag must have originally remained inside the furnace after most of the slag was tapped out. It must have been removed before the hearth was refitted for further use.

These findings indicate that separation of slag from the copper product was eventually accomplished in the larger bowl furnaces situated above the ground surface once a sufficient number of tuyeres were added to produce the blast required to achieve the 1,200 degrees C temperature needed to accomplish this task. The slag free bottoms of these furnaces indicate not only the formation of true ingots but also partial recycling of the lower sections of the furnace.

Shaft Furnaces

At Timna Site 2, there were two main phases of copper smelting; the earlier phase in Layer II, was dated to the 14th to 12th centuries B.C. and a later period in Layer 1 was dated to the 12th century B.C. Furnace II in Area G was built into a shallow pit, dug through several working floors of earlier metallurgical activities in Layer II. Furnace II was a semi-circular low structure built of dolomite rocks, its straight sides and flat bottom lined with a layer of clay mortar 2-3 cm thick (Rothenberg 1985:139, 145 and 146). The stone walling was left open at the front and must have been closed by a thick layer of clay mortar. This arrangement facilitated the proper servicing of the furnace; tapping slag, removal of the smelting products, which remained in the furnace after tapping and refitting for further use. A stone paved working floor was laid behind and beside the smelting hearth. In front of the hearth two 80-100 cm long stone slabs standing on edge flanked a shallow slag tapping pit, apparently for the protection of the smiths working the furnace. The front part of the hearth was only partly preserved near the furnace bottom and had the shape of a low ridge of hard-burned clay, separating the higher furnace bottom from the lower slag pit. Even the lower half of the actual tap hole was still preserved in Furnace II.

The smelting hearth had an inner diameter of 40 cm and was preserved to the height of 35 cm. Both sides and the back wall of the hearth were preserved up to the present ground level and were heavily slagged with a conspicuously thick slag layer adhering to the upper half of the back wall. The bottom was flat, somewhat eroded, and showed no signs of any slagging. There also was no slag or lining adhering to the lower parts of the furnace walls. About 30 cm from the pit's bottom, several fragments of a tuyere were found in situ, its original shape still clearly discernable: a clay tube of 12 cm diameter and 20 cm long, which penetrated the furnace wall at an angle of 25-30 degrees to the horizontal and its aperture into the furnace was at a height of 20 cm from the furnace bottom. Located next to Furnace II was a heap of ring shaped, tapped slag cakes, each with a cast-in hole in its center (Rothenberg 1985:146). Whenever slag of Late Bronze Age was found in Timna sites, it was always of this peculiar shape and weighed between 15-20 kg.

A rock-cut smelting furnace with a tubular tuyere at the back excavated at Area Z of Site 2 produced ring-shaped slag cakes in an attached slag tapping pit also cut into rock. Furnace IV in Area C of Site 2 is the only furnace found which showed signs of having the possibility of more than one tuyere (Rothenberg 1985:147). It was heavily slagged on the upper half of at least three of its walls, indicating the possible position of three tuyeres. This assumption is based on the observation that a heavy slag build up is normally formed on the furnace wall right above and on both sides of a tuyere. Apparently, as there was not a trace of any penetration of these additional tuyeres through the well preserved, slag covered furnace walls up to the height of 40 cm, the additional tuyeres must have penetrated the smelting hearth at the level of the stone-paved working floor or above. However, one fragment of a clay tubular tuyere was found in situ in the back wall of Furnace IV sticking to heavy slag incrustation 26 cm above the furnace bottom. The slag heap next to Furnace IV contained the same ring-shaped slag cakes as found next to Furnace II. In spite of the possible differences in the construction of Furnace II and IV, their operational principles were apparently the same and there is archaeological evidence for their identical age.

The return to the use of a single tuyere in these newer furnaces could have only been made possible with the introduction of some new device that could produce the blast needed to achieve the higher temperatures need to melt the slag. That device was the bellows depicted in a wall painting from the tomb of the vizier Puymre in Thebes dated to 1500 B.C. which shows the heating of a crucible in a large furnace with two tuyeres into which two sets of hand held bellows were inserted. “The bellows were brought to Egypt by the Hyksos people from the east in the first quarter of the second millennium B.C.” (Zwicker et al.1985:105).

These findings indicate that once slag separation had been accomplished, only a short period of a few centuries was required to perfect the technology to the point that repeated use of the same furnace became possible. These new shaft furnaces with their slag-tapping capabilities lead the smiths to the production of increasingly refined ingots.

Ingot Casting

Evidence from Timna Site 2 indicates that initial thin and smooth saucer shaped ingots quickly evolved into the “oxe hide” plano-convex shaped ones found ubiquitously throughout the Eastern Mediterranean Region in the Late Bronze Age. The blistered side of the plano-convex shaped ingots, which resembles oxe hide in its appearance, reflects the effects of molten copper being poured while in an oxygen rich atmosphere. The thin and smooth saucer shaped ingots lacked this “oxe hide” appearance due to its being formed in a reduction atmosphere found at the furnace bottom. Once the ability to tap the molten copper from the bottom of the furnace was accomplished, the casting of uniformly shaped plano-convex ingots became possible. Although no archaeological evidence for furnaces with this type of capacity have been found in any Timna site, portions of the moulds used to cast these ingots have been found in Level I of Timna Site 30 (Rothenberg 1985:134).

Tin-Bronze

As the arsenic-copper alloy began to cause significant health problems for the smiths during the first few centuries of the Early Bronze Age, the search for a new alloying agent, that could produce the same desired benefits of increased strength and beauty, resulted in the mixing of many different metals to determine their miscibility (blending) qualities. As tin is relatively easily reduced in a crucible due to having a melting point even less than copper, its manipulation was possible with the technology available during the Early Bronze Age. The oldest tin-bronze artifact known is an axehead from Ur, in Iraq, dated 3500-3200 B.C. and made of a 11.1 percent tin-copper alloy. The first tin bronzes rarely contained significant amounts of arsenic and the arsenic-copper alloys were usually free of tin indicating a clean break with the use of arsenic once the benefits of tin as an alloying agent was discovered.

Physical and Mechanical Properties of Tin

Tin, like copper is soft, pliable and non-toxic. When the two were mixed their miscibility permitted formation of an alloy that was equal in strength and hardness to that of the arsenic-copper alloys. This new alloy's resistance to corrosion was even superior to that of the arsenic-copper alloy. Small amounts of tin's most common form, cassiterite, occurs in the gossan level of some copper deposits due to tin oxide being insoluble. Of a generally dull brown color with no flame color produced, it may have been accidentally introduced into the charge as a mistaken brown iron oxide, which was used as a fluxing agent (Charles 1985:26-27). The production of a material straight form the furnace with strength superior to copper alone caused the smith to search for the responsible agent. Cassiterite is quite dense and therefore heavier per unit size than iron oxide and the differentiation between the two would not have been difficult to recognize. Tin like arsenic also endowed upon copper a beautiful golden color. A higher percentage of tin was required to achieve this effect than was needed with arsenic. A one to nine ratio of tin to copper was required to get the same golden color produced by just two percent arsenic.

Tin Mining

Placer deposits in dry stream beds draining away from metallic ore outcrops were the most likely location in which initial sources of any size were to be located. However, tin deposits near the parent material were much less common than copper (comprising just 0.01 percent of the outcrop's total mass) and the little that was available was quickly consumed due to the high demand for this material once its benefit was discerned. The world's supply of tin is located in a few isolated spots where extended weathering over geologic time has resulted in the movement of this insoluble material well away from the parent rock and re-deposited it in deep alluvial sediments. The greatest concentrations of tin are found in Malaysia, Thailand, Indonesia, the British Isles and Bolivia (Brandes 1983:7-7). Tin being considerably more rare in any given location than copper caused it to become a highly sought after commodity. "The rarity of tin, found in quantities in only a few places in the world, contributed to the development of long distance trading routes. The standard 10 percent tin-bronze common in Southwestern Asia in the Late Bronze Age indicates that tin had become readily available through trade" (Tylecote and Merkel 1985:20).

Alloying Processes

Once refined tin and copper became regularly available, it would seem that it was a relatively simple matter for the smiths to just mix the two highly pure minerals directly together in their molten state to produce the desired tin-bronze content. However, there are so few finds of any type of tin smelting furnaces or tin ingots in the archaeological record, that Charles suggests "Cassiterite stones were probably the source for most of the tin and simply added in crushed form directly onto the copper charge below the charcoal. Reduction is in fact more easily achieved in the presence of copper, since the copper in dissolving the tin away from the reaction (decreasing its chemical activity) increases the thermodynamic driving force for the reduction reaction and it is achieved at lower temperature" (Charles 1985:27). Therefore, Charles suggests when searching for signs of tin-copper alloying in the archaeological record look for the dull brown cassiterite rocks.

In a 1976 experiment, Friede and Steele were able to reconstruct a tin smelting furnace based on archaeological finds in Nigeria and South Africa (as cited by Tylecote and Merkel 1985:13). This furnace consisted of a shaft 60 cm high and 13 cm in diameter with one tuyere. Ore with a tin content of 6.3 to 30.88 percent was used with the latter producing tin prills and larger masses but nothing close to a plano-convex ingot despite the saucer shaped bottom of the furnace. Temperatures as high as 1,000 degrees C were needed and care was taken to see that all the charcoal was burnt away to keep the tin prills from coalescing with the fuel material. The purity of the tin prills produced was in the range of 98.8 to 99.15 percent. This data clearly indicates that contrary to Charles' position tin could have been smelted near ore deposits and transported as ingots.

Smithing Implements

The Friede and Steele experiment suggests that tin smelting was feasible with the technology available to the Early Bronze Age smiths. Archaeological evidence from Mercer and Thermi dated to 3000 B.C. indicates that crucibles containing molten materials were being handled during this period. "The addition of a boss to crucibles, which was a small indentation of about one cm located on the side into which a clay covered rod could be inserted, allowed the crucible to be raised and rotated to facilitate pouring of the molten metals" (Tylecote 1992:23). Whereas, the addition of locally available cassiterite ore directly into the process of smelting copper as proposed by Charles remains a possibility, the transport of heavy cassiterite ore long distances does not seem as plausible. After being smelted to a purity of around 99 percent, tin could have been transported in a highly guarded fashion due to the extremely high value it had become to the industry.

Either way, once lead was added to the tin-copper alloy, a compound was formed that in its molten stage was extremely fluid thereby allowing it to be easily poured. With the availability of such a user friendly tin-lead-copper alloy, the smith’s long held tradition for cold working metals could give way to the casting of bronze into moulds.

The advent of tapping molten copper directly from the shaft furnaces to produce the uniformly shaped plano-convex ingots was made possible once the proper tools were designed that could handle the extremely hot materials. Whereas copper could be melted in crucibles at a mere 950 degrees C, molten copper from the shaft furnaces were at the minimum 1,084 degrees C and typically more in the 1,100 to 1,200 degrees C range that was required to melt the fayalite slag. A crucible, found at Serabit dated to 1550 B.C., which had a rounded surface on the bottom and a hole at the pouring end would have allowed its contents to be emptied into a mould embedded below the ground level when rotated about 40 degrees to the horizontal. Pouring crucibles of many forms began to appear throughout Southwestern Asia at this time. Elongated bowls with lips that were held by withies (long poles) carried by two smiths are depicted in a tomb painting at El Argar. Both triangular shaped and round crucibles with flat bottoms were found throughout Southwestern Asia at a slightly later date.

Mould Casting

Initially single-sided moulds were used and some hammering was still required to bring the objects to the desired shape. “Steatite and clay were used to make early moulds as they could be easily carved" (Tylecote 1992:39). Despite preheating the clay moulds to help prevent thermal shock when filled with molten materials, fragments of these moulds as opposed to complete forms dominate the archaeological picture. Single-sided stone moulds that evolved from these fragile clay types proved to be much more durable, as many complete moulds have survived in the archaeological record. Due to their ability to hold more molten material without cracking, stone moulds could produce more massive objects than had previously been possible with the clay and steatite moulds.

With the invention of bivalve moulds more refined objects could be produced than was possible with just the one-sided moulds. "One two piece stone mould from Susa (3000-1000 B.C.) was intended for four tanged arrowheads" (Tylecote 1992:40). Molten bronze was poured into these two piece stone moulds through a clay runner bushing stuck into the moulds at their parting line. Eventually bronze bivalve moulds replaced the bivalve stone moulds throughout Southwestern Asia. Even more refined objects could be produced with these metal moulds due to the ability to cast into their construction dowels and holes that permitted very precise registration of the two halves. Although even more resistant to thermal shock than the stone moulds, bronze moulds were quick to deteriorate as a result of the welding of molten materials to their inside surfaces. Clay continued to be utilized in conjunction with both stone and bronze moulds in order to produce a variety of socketed weapons and agricultural implements.

Tylecote believed that bronze moulds may have merely been used for wax casting. "Lost wax casting involves making of wax patterns in pattern moulds, or carving them, and investing them in a sand-clay mixture, which is dried. The wax is then melted and run out, and molten metal is poured into the preheated mould" (Tylecote 1992:40-41). An alternative method of lost-wax casting involved a process known as "piece casting." A model of the desired object was roughed out in clay and then covered with wax onto which finer details were carved. An impression of this model was then taken by impressing square blocks of wet clay upon it until the whole pattern became enveloped in individual bricks. Each individual piece was secured to surrounding pieces by means of mortices and tenons to ensure the structural integrity of the impression being made. The combined model and block impression was then baked causing the wax to run out, thereby creating a mould for bronze casting in its place. These casting methods are similar to the techniques employed by the smiths that were observed at Ban Pba Ao, Thailand.

Summary

While copper's beautiful luster was likely the cause for initial human attraction, the material's ease in working to desired form was the likely reason for its incorporation into the human toolkit. Although working copper with hammerstones led to formation of cracks, these could be easily removed through heating the item in an open flame. This recognition of the material's malleability under heat led to further human manipulations of not only the pure native copper nodules but the various copper ores as well. With the systematic manipulation of copper through cold hammering and heat treatment to produce items of adornment and simple tools, humans entered the Chalcolithic period.

Native copper and higher quality oxide ores could be fairly easily melted in ceramic crucibles under a glowing charcoal fire to produce nearly pure metallic copper. As the materials available at the surface of copper deposits became fully consumed, humans faced increased difficulties getting copper from the more complex ores located in progressively lower levels. As carbonate ores began to be used, impurities in the form of a thick slag began to envelop the copper product during the smelting process. With the addition of fluxing agents designed to make the unwanted slag content less viscous, sufficiently high quantities of copper could be extracted from the carbonate ores. It had been discovered by the end of the Chalcolithic, that intensely heating pre-roasted azurite or malachite ore in a crucible under charcoal drafted by an air blast produced through tuyeres could reliably produce the 1,084 degrees C temperature needed to agglomerate copper to levels similar to native copper.

The first appearance of arsenic-bronze coincided with the first smelting of sulphide ores as a result of the level of human consumption of materials from local copper deposits. At this juncture, simple extraction techniques were no longer possible and deep mining operations were being required in order to obtain the sulphide ores. The deleterious effects of both mining and the use of arsenic as an alloying agent resulted in a depression in the copper industry at the beginning of the Early Bronze Age. The discovery of tin as a comparable alloying agent for producing bronzes within a short seven centuries served to save the industry from its possible extinction. Solving the problem of getting the sulphide ores to efficiently release their copper would prove to be a much more formidable obstacle.

The need to flux lower quality ores with hematite eventually changed to the need to use a silicate based flux as the sulphide ores located progressively deeper in deposits began to contain more and more iron themselves. This in turn resulted in the production of more and more unwanted slag materials. Simple hole-in the-ground furnaces were employed to smelt these sulphide ores due to the need to tear the furnace apart after each use. Separation of slag from copper product was not possible with this type of a furnace until a sufficient number of tuyeres were strategically placed to bring the internal temperature of the entire furnace up to the 1,200 degrees C needed to melt the slag.

The ability to tap off the liquid slag led to a dramatic increase in the purity of the copper ingots that could be produced. Within a couple centuries of this discovery, furnace design evolved rapidly until reusable shaft furnaces blasted by bellows had been developed. The quantity of copper that could be efficiently produced by this type of furnace led to the florescence known as the Late Bronze Age.

CHAPTER III

THE EAST ASIAN BRONZE AGE

Thailand's Bronze Age can be understood only in the broader context of the Chinese Bronze Age. "In interpreting the archaeological record in terms of cultural change, it is important to determine in which direction each change spread and, as nearly as possible, where it originated within the area being studied" (Rowe 1962:41). By the process of diffusion, metallurgy spread from the Huanghe River Valley of Northern China into the Khorat Plateau of Northeast Thailand within the span of the second millennium B.C. (figure A-1). Although independent invention remains a possibility, substantial archaeological data exists in support of diffusion as the primary change agent as far as Thailand is concerned.

Earliest East Asian Metallic Artifacts

China's earliest known metallurgically produced artifact is a 6 - 10 percent tin-bronze knife from Linjia located in the Gansu region of the Upper Huanghe River valley. The site belonged to the Majiayao phase of the Yangshoa culture indicating occupation around 3000 B.C. (Higham 1996:43). The knife was found in a storage pit together with 1.8 cubic meters of the cereal grain millet. Fragments of metallic residue found in other pits at the site suggest the possibility of local casting, but the lack of additional evidence for metallurgical activity indicates otherwise. “Only one further metal item has been recovered from the Machang phase, a fragment of a second knife from Jiangjiaping. This has been reported as a copper-tin alloy” (Higham 1996:44-45). This site is also located in the upper reaches of the Huanghe River not to far from Linjia.

The Machang phase of the Yangshoa culture is dated from 2400 to 2000 B.C..

These two isolated finds do not appear to be just the result of sampling error. Numerous large Yangshoa age cemeteries, with the Liuwan site containing 1500 burials, have been excavated without producing any further evidence of metallic items. The same is true of cemeteries located in the Shandong region located in the lower reaches of the Huanghe River, which belonged to the contemporaneous Dawenkou culture. The presence of increasing amounts of exotic jade as grave goods in late phase Dawenkou cemeteries suggests that high status individuals were beginning to emerge by 2400 B.C. in the lower Huanghe River valley. Although jade was not found in any Yangshoa cemetery, one possibly high status individual from the Machang phase was identified at Liuwan by the inclusion of over ninety pottery vessels as grave goods, when the norm was just a few grave goods. Given the exotic nature of tin-bronze, if it had been readily available to these communities along the Huanghe River, it should have been included as grave goods of those individuals who enjoyed high social standing.

The sudden appearance of an alloyed item from the middle of the sequence previously described in the chapter on metallurgical processes clearly suggests diffusion as the change agent. "The usual situation is that inventions are made one at a time. However, once a series of inventions has been made and the new items have spread over a large area, they may become associated with one another as parts of a single cultural pattern. Then the associated features are very likely to be transmitted as a unit. The association of several features in an area should therefore suggest to the investigator that he is dealing with a pattern introduced from some outside source" (Rowe 1962:42). The paucity of bronze items, found in the Huanghe Valley during the third millennium B.C., suggests that it was the actual items themselves that were brought in as trade goods rather than the technology required to produce them. As the alloying of tin and copper had been accomplished in Southwest Asia since 3500 to 3200 B.C., it is reasonable to suggest this location to be the origin of these earliest knives found in the Huanghe valley. "Trade pieces provide some of the best evidence of contemporaneity, and some trade is likely to occur between neighboring areas even in time of relative isolation" (Rowe 1962:50).

Evidence of an Indigenous Origin

Evidence of a possible indigenous origin for copper working is revealed in the archaeological record of the Qijia culture, which evolved out of the Yangshoa culture in the Upper Huange Valley. Radiocarbon dates from four sites belonging to this culture suggest their settlements were occupied between 2300 to 1800 B.C.. Storage pits at the Qinweijia site yielded copper based objects including two rings, an awl, axe and two thin discs with a hole at one end (Higham 1996:48). One of the rings and the axe contained lead as an alloy with the rest made of copper alone. Two copper fragments, possibly knives, were found in the occupational site at Dahezhuang, one with millet grains still adhering to it. The latter item was radiocarbon dated to 2000 B.C. (Higham 1996:49). At Huangniangniangtai, thirty two copper based items were recovered from both occupational and cemetery contexts. These included knives, chisels, a ring, and various flat pieces of metal. No evidence of alloying was reported for any of these items. The only tin-bronze items reported from this culture were two bronze mirrors, one from

Qijiping and one from Gamatai, the latter containing 9.6% tin. These bronzes were not from contexts having a secure provenience and no radiocarbon dates were offered. The bronze artifacts looked extremely similar to later Shang mirrors and therefore were probably not related to the Qijia cultural sequence (An Zhimin as cited by Higham 1996:49).

Emergence of Social Stratification

In the Shandong region of the Lower Huanghe River valley, the culture evolving out of the Dawenkou culture and contemporaneous with the Qijia culture represented a marked change in the nature of Chinese prehistoric society. They were the first to build wall enclosed centers, indicating a new capacity to marshal a considerable labor force. One such site, within one hundred km of the Huanghe's mouth, was Chengziyai. Walls 13.8 m wide at the bottom, 9 m wide at the top and 6 m tall enclosed an area measuring 450 x 390 m. These were made from layers of stamped loess soil, which were inclined inward with each addition. It is estimated that 115,000 cubic meters of soil were moved to create these walls. "Given the defensive nature of such an enterprise, it is not to surprising to find that a high proportion of the bone and stone implements at such sites are projectile points" (Higham 1996:50).

This culture found in the Lower Huanghe Valley became the Longshan, which besides establishing a string of walled centers developed a mortuary pattern that clearly signaled a change from an egalitarian to a more hierarchical social organization. The cemetery at Chengzi, located approximately 100 km to the southeast of Chengziyai, contained three distinct classes of burials. Rich graves were distinguished by a soil ledge that completely surrounded the coffin onto which tall-stemmed ceramic cups and pig mandibles were invariably displayed. A second class of graves contained some but not all of these features, while a third class of graves never contained ledges and only meager grave goods. Ceramic items first began to be produced on a potter’s wheel at this time. (Ronan and Needham 1978:26) Metal items were not found in any location belonging to the Longshan culture in the Shandong region.

In the middle reaches of the Huanghe River valley, Longshan sites yield similar evidence for structural changes in the organization of society. Several walled centers were established at Pingliangtai, Hougang and Wangchenggang. Within a stamped earth fountation of this latter site were found human skeletons suggesting their possible sacrifice. "Chang has suggested that these were house foundations for the upper echelon of the Wangchenggang community, a group which was acquainted with copper metallurgy, for a fragment of a bronze vessel containing copper, tin and lead was found in a period IV pit there. A radiocarbon date from this period has been obtained: 2878-2104 B.C." (Higham 1996:52).

Some sites became very large during this period. Taosi, located on a tributary of the Huanghe, covered an area of 300 ha. Of the thousand plus burials in the cemetery at this site, nine individuals stand out as exceedingly rich. One of these individuals had 200 offerings including jade rings, stone axeheads, finely painted pottery and musical instruments including a wooden drum with a crocodile skin tympanum. There were eighty second class graves that contained sets of ceramic vessels, jade axes, jade tubes and jade rings along with pig mandibles. The remaining burials were extremely poor as they contained few if any grave goods. In the entire assemblage from this cemetery, only one metal object was found, a bell comprising copper alloyed with one and a half percent lead. Although the burial with which it was associated was not identified as to class, a bone from it was radiocarbon dated to 2615-1890 B.C. (Higham 1996:52).

In the nearby site of Meishan, the first definitive evidence of copper melting or smelting in the Huanghe Valley was revealed. In a domestic setting were found two crucible fragments with metal still attached to interior surfaces. The crucibles have been radiocarbon dated to 2290-2005 B.C. and the metal found to be ninety five percent copper, with the content of the remaining five percent unreported.

The meager evidence presented above provides additional evidence for the possibility of an indigenous development of copper metallurgy within the upper and middle reaches of the Huanghe River Valley from 2300 to 2000 B.C.. The pausity of metal items found over this large region might still suggest an exotic origin if not for the fact that nearly all items of the period are made exclusively of copper. Those items that had been alloyed with lead were surely not as attractive as copper alone and both were considerably less attractive than tin-bronzes. Given the early stages of their metallurgical development, the local production of bronzes is highly unlikely. Procurement of bronze items would remain most likely possible only through long range trade. The presence of a few isolated bronze items during this period suggests that any long range trade which existed was based primarily on chance. With the low demand for copper based items that is evidenced in the archaeological record of this period, there was clearly no driving force to compel the development of more formal long distant trade in this commodity.

Jade versus Copper as a Status Symbol

Whereas copper and especially bronze production requires extensive technological skill that as previously described is slowly and laboriously acquired, that needed for the transformation of jade into a finished product was within the repertoire of those who could grind and polish stone. The skill needed to grind and polish stone had been present since the beginning of the Chinese Neolithic many millennia before. Gaining control over the exchange of an exotic good such as jade which could be acquired only through long range trade would elevate the individuals involved into positions of considerable power. The establishment of secure trade relationships increased the availability of the desired item and a reliable supply helped to ensure that an increase in demand would be met. When such an economic enterprise became entrenched within a particular lineage, the subsequent development of an hierarchical social structure is likely to emerge based on power and influence differentials.

The archaeological record of the third millennium B.C. along the Huanghe River valley indicates that just such a transformation in society did occur. The appearance in the lower reaches of this river valley of walled defensive centers and evidence of large scale violence together with the use of jade as grave goods to the complete exclusion of copper objects indicates that jade was a highly valued commodity while copper was not. The absence of walled defensive centers and evidence of large scale violence in the upper reaches of this river valley where copper based items were more plentiful indicates that copper did not serve the same mechanism as jade for signaling social differentiation.

Rise of Centralized Power

The site of Erlitou located along the Huanghe River valley where the North China plain meets the first western steppe represents a pivotal node in Chinese prehistory. Four phases in this site's archaeological sequence yield a dramatic picture of the multitude of changes that occurred in Chinese society during the first half of the second millennium B.C.. The first and second phases represent a continuation of the Longshan associated features of stamped earth foundations and individual graves with variable amounts of jade as grave goods. However, for the first time on the North China plain, some of the larger graves yielded bronze bells (Zhao Zhiquan as cited by Higham 1996:55). In Erlitou’s early domestic contexts, pottery kilns and crucibles for pouring bronze along with bronze awls and knives were reported. Radiocarbon dates of 1900 B.C. are given for the initial settlement of the site. The *hsien* pottery vessel with its unique tripod base became part of the ceramic assemblage during the transition between the Xia and Shang Dynasties that occurred in the seventeenth to sixteenth centuries B.C. (Ronan and Needham 1978:25).

It is during Erlitou's third and fourth phases that a remarkable florescence of social development was noted. Within the center of a large walled area measuring 100 by 100 m is a foundation for a large building measuring 30.4 by 11.4 m whose roof was supported by 22 columns. Access into this structure was gained through three passages, each of which were flanked by rectangular chambers. On the south side of this walled center was an industrial site containing crucibles and casting residue. "Burials described as medium and small elite graves have been found outside the site perimeter" (Zhao

Zhiquan as cited by Higham 1996:55). Grave goods included bronze cups on tripod legs (*jue*), bronze dagger axes (*ge*), bronze battle axe (*qi*), bronze halberds, bronze knives, and jade ceremonial axes (*yazhang*). There was no evidence that top elites were buried at this site. Bronzes were also found in non-burial contexts. These included adzes, chisels, battle and dagger axes, knives and a series of circular discs and plaques embellished with turquoise inlay. The metal items were tin-bronze, some having small amounts of lead as well. “The bronzes and jades from later Erlitou reflect an interest in ritual, feasting and display, both in the court and in war. Whether this site should be ascribed to the Xia or Shang, or indeed to both with a break between phases II-III, the fact is that at Erlitou, we encounter the transition to a society based on a central walled palace, a core element in historic Chinese civilization" (Higham 1996:56).

Shang Dynasty

Erlitou was but one of five walled centers in which the Shang established their capital. Xiao, within the limits of present day Zhengzhou, was an extremely large site covering 25 square Km with a walled area encompassing 318 ha. It is estimated that one and a half million cubic meters of soil would have needed to be moved to construct this site’s wall, which stood 9 m tall and had a 22.5 m basal width. A centralized building foundation measuring 1000 square meters is the largest structure known from the Shang period. Two workshop areas located outside the city walls yielded much evidence of bronze smelting. These included crucible fragments, bronze detritus, slag and ceramic moulds. Separate workshops were identified for ceramic and bone working. Among the bones in the workshop that manufactured projectile points were human bone. (Higham

1996:57) Cemeteries yielded many bronze vessels, jade and pottery offerings but again there is no evidence of the interment of top elites. "A cache of bronze vessels has also been found outside the city wall, one specimen, a *ting* tripod, weighing 86.4 kg" (Higham 1996:58).

It is at the capital city of Yin, located just northeast of present day Anyang, that the royal necropolis of Xibeigang was found. The twelve kings who ruled from Yin are located there along with an additional 2500 burials. Eight of these kings are buried in the western sections of the cemetery while four are buried in the eastern section. All royal tombs are heavily looted but much can be discerned from their layout and the tombs of lower echelon elites. The royal graves were comprised of a rectangular subterranean chamber, approached from the four sides by a ramp. One such tomb was ten meters deep and covered an area of 330 square meters. Despite the looting, there was evidence that all royal tombs contained sacrificial human victims, horses, chariots and many bronze items. One bronze cauldron from tomb 1004 weighed an astonishing 879 kg.

Twenty tombs containing secondary elites have been identified, several of which has been found intact. Their contents reveal some idea of the wealth that must have been contained in the royal tombs. One contained 440 bronzes and 590 jade items. The tomb of burial 18 revealed that the lacquered wood coffin was placed inside a laquered wood mortuary chamber, the latter with black designs painted on a red background. Between the coffin and walls of the mortuary chamber were four sacrificial human skeletons. Grave goods consisted of four ceramic vessels, 19 bronze weapons, 24 bronze ritual vessels, 11 jade objects, 28 bone artifacts and 4 cowry shells. "Thirteen of the bronze vessels were inscribed, identifying the owner as Lord Ziyu, whose name appeared on oracle bone inscriptions as a member of King Wuding's lineage” (Higham 1996:58). All twenty of these secondary elite burials were identified on the presence of sacrificial human remains in association with bronze grave goods and relatively large mortuary chambers that lacked ramps. Sixty graves are ascribed to tertiary elites by the presence of bronzes in coffins that lacked placement in a mortuary chamber. "The vast majority of graves fall into the fourth group, in which no bronzes were found, and the body is contained in a wooden coffin with one or two pottery vessels. About ninety of the burials lacked any grave goods. The formality of the cemetery contrasts with the disposal of what the Chinese archaeologists refer to as slaves: they were interred with little ceremony, and more often than not with no grave goods, in refuse pits" (Higham 1996:59).

Several significant features appear together for the first time during the reign of the Shang Dynasty. It was with the inscribed oracle bones at Anyang that the first evidence of Chinese writing is found. "The oracle bones were used for scapulimancy, a divination technique that involved heating the shoulder blades of mammals or the shells of turtles with a red-hot poker and discerning the reply of the gods from the shape and directions of the cracks. It seems to have been a method peculiar to the Anyang area and to have started just a little before the arrival in 1520 BC of the Shang dynasty” (Ronan and Needham 1978:26-27). The second feature is the use of cowry shells as a form of currency. “Where the cowry shells came from is still uncertain: the Pacific coast south of the Yangtze estuary seems probable. Yet the Shang ruled over only a restricted area, perhaps spreading no more than 300 km in any direction from Anyang. Theirs was a feudal society in which matriarchal traces had given place to patriarchal control, where there was family or ancestor worship, and human sacrifice" (Ronan and Needham 1978:29).

The Shang Dynasty brought about many significant changes in the Chinese social fabric. These changes were predicated on the ability of the Xia Dynasty to manufacture the first bronze objects around 1900 B.C. Within the first few centuries of the second millennium B.C., the value of bronze as a tool for use in ritual display had became just as important as that of jade. The outstanding quality and quantity of the Shang Dynasty master pieces would suggest that bronze had become the primary method to display status during the last half of the second millennium B.C.

Yangzi River

Movement down the coast from the mouth of the Huanghe to the mouth of the Yangzi would not represent such a great feat for the capable people of the Longshan culture. Their contact with the Liangzhu culture is indicated on the appearance of a rich grave at Sidun located near the mouth of the Yangzi that contained 24 jade rings and 33 jade tubes (*cong*) and the same cups on long stemmed pedestals seen at Chengzi on the Huanghe (Higham 1996: 68). Relatively easy movement would have been possible down the broad Yangzi River to the Lake region located in this river's middle reaches. Two sites in the Lake region that yielded the earliest copper based items found in the Yangzi Valley are dated to the Shang period. The first is a tomb at the site of Xin'gan located 50 km below Lake Poyang on the Ganjiang River. "The tomb included many items wrapped in silk, while others were deliberately broken before being stacked within the grave. Apart from numerous ritual vessels, there was a bronze stepped anvil weighing 20 kg, and the earliest identified bronze socketed ploughshare. The application of bronze to agriculture was also seen in socketed shovels. Numerous jade items were also recovered, including knives, sprearheads and rings" (Higham 1996:69). The second site is Panlongcheng located at the confluence of the Yangzi and what Higham identifies as the Han River that flows northward thereby connecting the Yangzi with the middle reaches of the Huanghe (Higham 1996:68). At this site Shang style vessels, halberds, knives and axes were recovered.

Beijiang River

The headwaters of the Ganjiang are a mere 20 km from those of the south flowing Beijiang River that empties into the Zhujiang River located within the region of southern China known as Lingnan. The site of Shixia located in the headwaters of the Beijiang River contains evidence of three phases. “The lowest, dated 2850 to 2500 B.C., incorporated a cemetery in which 108 burials have been excavated. Offerings include pottery vessels in a wide range of forms some of which find precise parallels in contemporary Liangzhu cultures to the north. The stone implements and jewelry also recall northern, Liangzhu forms particularly the *cong* tubes and bracelets, pendants, hairpens and slit rings” (Higham 1996:84). The sequel to this intrusive settlement is seen in the 32 burials of the second phase. Grave goods include thin walled ceramic vessels that could only have been made on a potter’s wheel. A significant range of bronzes were found in the non burial context within the upper level of the Shixia site. The bronzes belong to the Western Zhou's Spring and Fall period (1122 to 700 B.C.) and include a short sword or dagger, an axe, awl and scrapers. “These stray finds and the upper context at Shixia suggest a vigorous exchange network linking Lingham with the Yangzi Valley and ultimately, with the Zhongyuan” (Higham 1996:90). The Zhongyuan is another name for northern region of China along the lower Huanghe River.

The Zhujiang Delta

At the Yung Long site located on Hong Kong Island, a cemetery dated 2650 B.C. yielded graves goods that included geometric decorated pottery, slit stone rings and jadeite ceremonial axes. The Hedang site on the mainland dated to the late third millennium also yielded pottery impressed with geometric designs and very finely worked bracelets and slit rings made from exotic stone.

The Zhujiang Delta's first copper based items with a precise radiocarbon date are from the Kwo Lo Wan site. A small cemetery there yielded two bivalve sandstone moulds for casting socketed axes together with two bronze projectile points, ceramic vessels with geometric designs, and slotted stone rings of marble and agate. "Dated by three radiocarbon dates between 1300 and 1000 B.C." (Meacham as cited by Higham 1996:96). "A further sandstone axe mould has been recovered from Tung Wan Tsai, associated with three radiocarbon dates derived from shell. These range between 1701 and 927 BC" (Rogers et al. as cited by Higham 1996:96). Although not dated, nearby Sham Wan yielded locally casted arrowheads and fish hooks made from 10% tin-bronze. "One of the best known bronze assemblages comes from Tai Wan, about 1.5 km north of Sham Wan. Finn has described two socketed spearheads from this site, as well as a socketed axe, both of which he compared to similar examples from Bac Bo" (Finn as cited by Higham 1996:95).

Bac Bo

The Phung Nguyen Culture existed near the confluence of the Red and Black Rivers in the Bac Bo region of present day Viet Nam from 2500 to 1500 B.C. The Phung Nguyen type site itself yielded over a thousand adzes or adze fragments, four shouldered and several stepped forms quite similar to southern Chinese styles, 540 stone bracelets, a few stone arrowheads and a bone harpoon in a non-mortuary context. "The degree of skill associated with the manufacture of stone jewelry is particularly clearly seen at Trang Kenh. Excavations have revealed a wide range of nephrite ornaments, including bracelets and beads, as well as the chisels, drill points, saws and grinding stones used in their manufacture. The radiocarbon dates being from 1679 to 1514 B.C." (Higham 1996:87). A cemetery at Lung Hoa contained 5 m deep grave pits and ledges around their base. Grave goods included bracelets, slit rings, beads, adzes and pottery in some graves while other graves contained only adzes and pottery. This distinction suggests social ranking based upon the importance of jewelry to the culture. The presence of a jade yazhang blade in the Phung Nguyen site and one at the neighboring Xom Ren site, which match up precisely with those found at Erlitou, provides indisputable evidence of contact by the early period Shang and the people of the Bac Bo region. (Tang Chung as cited by Higham 1996:87).

Exactly the same sequence and chronological framework is found for the initial appearance of bronze in the lower Red River Valley as existed for the Zhujiang Delta. At the Thanh Den site are found sandstone moulds and melting furnaces radiocarbon dated at 1500 to 1000 B.C.. At the contemporaneous Dong Dau site, located 35 km east of Phung Nguyen, the top layers of this deeply stratified site yielded sandstone moulds, tin-bronze axes, chisels, arrowheads, socketed spears and fishhooks. "The analysis of a sample of 22 Dong Dau bronzes has revealed an alloy similar to that in use in northeast Thailand at the same juncture in that no lead was employed. Tin levels, however, appear to have been rather higher with values varying between 6.8 and 28 percent and averaging 11 percent. Three arrowheads were made from an alloy comprised of copper and between 2.9 and 6.6 percent antimony with no tin. Small clay-lined furnaces have been found at Dong Dau" (Higham 1996:96-97).

Northeast Thailand

The Truong Son Cordillera lying between Bac Bo and Northeast Thailand represents a formidable boundary between these two regions due to its upland height. However, waterways run both east and west from it, which allowed travelers to traverse this divide without undue hardship. The most likely path would be down the Nam Ka-dinh on the western slope to its confluence with the Mekong River at the northeast corner of the Khorat Plateau. The Mekong runs across the northern part of the Khorat Plateau until it takes a ninety degree turn where it meets the Phetchabun Range. The site of Non Nok Tha lies on the eastern edge of the narrowest part of the Phetchabun Range. Non Nok Tha contains a cemetery assigned to the last half of the second millennium B.C. "The earliest graves might be as early as 2000-1500 B.C., but the majority, and this includes those containing bronze artefacts, are more likely to fall within the period of

1500-1000 B.C." (Higham 1996:191). Although nothing is found in the grave goods of the earlier period burials to suggest the exchange of exotic metal goods, the extent of the artifact assemblage in the latter burial group reveals a bronze manufacturing tradition quite smimilar to that seen at the same juncture in Bac Bo and Lingnan. “Although the site lies close to the Loei copper sources, of 217 graves or mortuary features, only nine contained bronze items” (Higham 1996:193). Three burials, both men and women, contained either sandstone moulds or crucibles as grave goods. One male burial contained both a crucible and a sandstone mould for making a socketed axe. Five socketed bronze axes were found all associated with males. "Crucibles of clay tempered with rice shaff ranged considerably in size. The smallest would have contained only about 200 g of metal, the largest 2.2 kg. Despite the size of the latter, the 79 artefacts found, together with the fragments and nodules of bronze, weighed just over 2 kg. All artifacts were alloyed, tin bronzes being the commonest, with the former accounting for up to 15 percent of the metal. But towards the end of the period, we also encounter an increasing interest in adding lead to copper” (Higham 1996:194).

Although no cemeteries with bronze as grave goods from the second millennium B.C. have been found in the southern regions of the Khorat Plateau, several other sites in the northern region have. "Non Praw located 30 km northeast of Non Nok Tha revealed an inhumation cemetery. As at Non Nok Tha, the earlier graves included shell disc beads, bangles and pottery vessels, but no bronze offerings were found. Bronze was found with later burials, including axes and bracelets. One of these axes had a crescentic shape identical to one from Non Nok Tha” (Higham and Thosarat 1998:112). The site of

Ban Chiang, located 110 km to east, also contained a cemetery with grave goods that included bronze bracelets, anklets, axes and socketed spearheads. "Two dates from in situ hearths in contexts where bronze was also present are 1118-891 B.C. and 1620-1409 B.C." (Higham 1996:198). As much controversy over the possibility of a 3500 B.C. date for this site has existed due to dating being based on charcoal taken from grave fill, the dates in the second half of the second millennium seem more reasonable in light of how they were obtained and their similarity with those of neighboring sites.

Central Thailand

Crossing the Phetchabun Range, which constitutes the western border of the Khorat Plateau, one enters Thailand’s broad central valley. Here there are numerous rivers that drain from the northern highlands to the Gulf of Thailand. The earliest known site yielding bronze artifacts from the central valley is Nong Nor. The site, located today 20 km from the Gulf of Thailand, was probably on the shoreline when habitation began in 2500 B.C.. A cemetery there containing 166 burials with bronze grave goods has been dated to 1100-600 B.C.. “ Burial 105 is a good example of a complete grave. A large bronze bangle was found on his right wrist, and a marble bangle on his left. The bronze example is particularly large, and matches almost perfectly one described for Ban Chiang. When preparing the skull, a dark circle in the area of the ear turned out to be the decayed remains of a tin earring. One woman was found interred with two spiral-form tin bracelets, one on each wrist” (Higham and Thosarat 1998:118-125). No information was provided to indicate whether the bronze and tin jewelry found in this cemetery was produced at the site.

Summary

The oldest known metallic artifact from Eastern Asia, found at Linjia in the upper reaches of the Huange River, was a bronze knife that has been dated to the early third millennium B.C.. The fact that it was made from bronze suggests that this object was likely imported rather than made by local smiths. Within the last half of the third millennium B.C., copper objects began to appear along with bronze objects in limited numbers in the middle and upper reaches of the Huanghe River valley. Evidence of local manufacturing found at the Meishan site consisted of a crucible with copper metal still adhering to its inside walls. It was not until the first century of the second millennium B.C. that evidence of indigenous production of bronze objects was found at the Erlitou site located in the middle reaches of the Huanghe River. This evidence consisted of crucibles and pottery kilns that were found in the site's early occupational zones. During the last half of the second millennium B.C., the Shang Dynasty produced numerous exquisite bronze masterpieces that were clearly used as status symbols by the top elites of the social hierarchy. In the occupational zones of the Shang capitol of Xiao, evidence of local manufacture of the bronze objects consisted of crucibles, ceramic moulds, slag and detritus.

Within the last few centuries of the second millennium B.C., evidence of bronze manufacturing began to appear along the coastline of Southeast Asia and on the Khorat Plateau located in the northeast of modern day Thailand. Bronze objects found in the sites on the Khorat Plateau were primarily items of personal adornment and simple utilitarian wares. Although most of these bronze objects have been retrieved from cemetery contexts, more is known about their method of production than is known about the manufacture of bronze objects during East Asia’s prehistoric period. The earliest site of Ban Nok Tha, for example, revealed that a rice tempered clay crucible and sandstone mould were included as grave goods along with bronze objects which matched exactly the design in the sandstone mould.

CHAPTER IV

PENINSULAR SOUTHEAST ASIA

The city of Ubon Ratchathani or simply Ubon is located on the Khorat Plateau in the northeast of Thailand, known locally as the Isaan region. Ubon serves as the administrative and commercial center of the Ubon Ratchathani Province, which comprises the southeastern most of the nineteen Isaan provinces. Over half of Ubon Ratchathani Province's one million and seven hundred thousand people live in Ubon and its largest suburb, Warin, making it the largest metropolitan center in Isaan. Situated at latitude fifteen degrees, thirteen minutes and fifty nine seconds North and longitude one hundred and four degrees, fifty one minutes and forty seven seconds East, the city lies approximately ten kilometers to the east of the confluence of the Mun and Chi Rivers at an altitude of one hundred and twenty three meters. The literal translation of the name Ubon Ratchathani is the Royal City of the Lotus flower.

Geographical Description

As the saucer-shaped Khorat Plateau tilts primarily towards the southeast, the Mun River serves as its primary drainage system from the west while the Chi River serves as its primary drainage system from the north. After flowing six hundred and seventy three kilometers, the Mun River empties into the Mekong River eighty kilometers to the east of Ubon. The Mekong River, serving as both the northern and eastern border between the Khorat Plateau and Laos, drains from the Himalayan highlands of Central Asia and empties into the South China Sea near present day Ho Chi Min City. Two smaller rivers, the Loei and Songkhram, flow north and east respectively into the Mekong River as they drain off the small Sakhon Nakhon plate, which is located on the Khorat Plateau’s extreme northeastern corner. The Dong Rak mountains form the Khorat Plateau’s southern border with Kampuchea while the Phetchabun Mountains form the western border with Thailand’s Central Valley.

Hydrological Conditions

Whereas, Thailand’s Central Valley averages two thousand millimeters of rainfall annually, the Khorat Plateau averages five to seven hundred millimeters less each year. This difference in annual precipitation is due primarily to the rain shadow produced by the Phetchabun Mountains to the west, the Dong Rak Mountains to the south and the Truong Son Cordilliera located to the east along the border between Laos and Viet Nam. These mountain ranges create a partial barrier to the monsoonal rains that inundate the rest of Southeast Asia during the summer months. As a result of capturing a large portion of the moisture that would have otherwise fallen upon the Khorat Plateau, these mountain ranges are covered with lush tropical rain forests. It is the difference in temperatures between the air masses over Central Asia and those over the South China Sea and the Indian Ocean that creates the seasonal monsoon winds. During the summer months starting in mid May and lasting through mid October, the hot air over Central Asia rises creating a vacuum into which the cool moisture laden air above the oceans to the south rush to fill. Resultant orographic winds flowing steadily from the southwest produce heavy rains as they cross over Peninsular Southeast Asia and the Indian subcontinent throughout this five month period. Cyclonic winds associated with centers of extreme low pressure which develop in August and September help to increase rainfall amounts to an even greater extent. During the winter months, Central Asia’s extreme cold causes its air mass to become dense and heavy, while the air over the ocean is warmer and lighter. This differential in density now causes heavy dry air to flow steadily from the northeast off the Asian continent towards the oceans to the south from mid October to early March. Not only is there less rainfall on the Khorat Plateau during the wet season, but the drought of the cool season and the hot season (March through May) is much more pronounced because of it being in the wake of the surrounding mountain’s rain shadow. The lofty Truong Son Cordilliera located to the east serve to effectively block off the northeast orographic flow during the cool season, while the convective flow off the Gulf of Thailand is blocked during the hot season by the Dong Rak range to the south. The average temperature range for the Khorat plateau is from 30.2 Celsius to 19.6 Celsius. The highest temperature recorded was 43.8 Celsius in the Udon Thani Province and the lowest was 0.1 Celsius in the Loei Province. Mean monthly maximum for the Ubon Ratchathani Province range from 30 Celsius during the wet season to 36 Celsius in the April, in the midst of the hot season. Mean monthly minimum range from 17 Celsius in January to 25 Celsius in May.

Geological Formations and Soils

The Khorat Plateau is formed essentially of sedimentary rocks deposited in fairly uniform horizontal beds known as the Khorat group. It is mainly a thick sequence of sandstone, siltstone and conglomerate. Even with the predictable rains of the southwest monsoonal flow, the sandy soils that dominate the plateau are quick to drain. Eight dams have been built during the last half of the twentieth century to help secure the water needed to support the region's growing population. Prior to this development, the region's population was required to live near the river drainage systems, particularly where smaller tributaries emptied into the larger rivers. Frequent flooding during the rainy season has resulted in the development of extensive flood plains, especially at the confluence of major rivers. Flood plain alluvial deposits consist of sand, silt and silty clay layers in alteration. "The low terrace main deposit is sand which contain laterite gravel as cemented sheets or as concretions imbedded in a layer of clay, while middle terrace consists of sandy sediments with slightly less clay contents in the surface layer and usually have laterite as more or less cemented sheet imbedded in a layer of clay. The laterite is commonly found at a depth of 50 to 100 cm below the ground surface" (Electric Generating Authority of Thailand [EGAT] 1992:27). As the average elevation of the Khorat Plateau is two hundred meters, the upper reaches of the Mun and Chi Rivers have multiple terraces on which very well developed humus-rich soils can be found. Deep red oxisols are the most common soils found in the uplands located above the sandy loams of the flood basins. The high level of salinity of the soil in certain areas allows salt to be extracted for commercial purposes. Along the Lam Siao Yai that flows into the Mun just upstream of its confluence with the Chi River, large deposits of salt have been extensively worked since the prehistoric period.

Incorporation into Thailand

The extreme variability of rainfall on the Khorat Plateau between the wet season and the dry season has resulted in the region being considerably less profitable for the production of rice and other agricultural products than the fertile and well watered

Central Valley of Thailand. Shunned by the Thais to the west, the cultural heritage of Isaan is predominantly Laotian. From the twelfth through seventeenth century A.D., the region was settled by Lao immigrants under the protection of the Lan Xang Kingdom of Vientiane. Although officially a territory of Siam since the mid fourteenth century, it was not until the reign of King Rama I in the last quarter of the eighteenth century that an attempt was made to bring the region under their administrative authority. With the founding of Ubon in 1786 by Thao Khamphong and its designation as the provincial center in 1792, the area's first official membership into the Kingdom of Siam was accomplished. Throughout the nineteenth century, forced population transfers of ethnic Lao to Isaan occurred under direction of the Siamese government. The distinct cultural separation from Central Thailand, combined with the region's lower economic status and the typically darker skin of its people has encouraged a racist attitude to develop against the Lao people of Isaan by the Thais of the Central Valley. The main language used in rural regions continues to be Isaan, also known as Mountain Khmer, but Thai is also widely spoken as is Khmer especially in those provinces along the southern border with Kampuchea. All three belong to the *Austroasiatic* group of languages.

Laotian Influence

While many distinct cultural traditions of the Lao continue to be observed in the cuisine, dress, customs and language, it is perhaps their unique festivals that clearly set the people of Isaan apart from the rest of Thailand. Each year in July, Ubon celebrates a week long candle festival in which large candle floats are paraded through the streets day after day to illustrate the fleeting nature of existence. The wax sculptures start out exquisitely molded and carved to great detail in order to depict mythological beings and cultural heroes only to melt down day after day in the hot sunlight until they become nothing more than formless lumps of wax. At the end of the week long parade, practicing faithful join the local Buddhist temples to become monks or nuns for a period lasting three months. The tradition has its roots in the economy of rice cultivation as this three month period corresponds with the time that rice can grow on its own during the rainy season. Another festival unique to the area is that of the rocket festival, Bun Bang Fai, which occurs near the end of the dry season in either late May or early June. Each farming village builds a large rocket which is ceremoniously launched into the building cumulus clouds that signal the coming rainy season. The intent of shooting the rocket into the clouds is to impregnate the cloud with power from the rocket so as to produce the heavy rains needed to grow the newly planted rice sprigs. In the project site of Ban Pha Ao, located twenty five kilometers north of Ubon, a brightly decorated rocket was rolled on a wagon through the village's main streets, blessed by the village's most venerable priest, and then aimed up towards the heavens in a most auspicious manner by the village's elite. The hopes of the entire village accompanied the rocket as it lifted off the ground with loud cheering emitted and a multitude of fireworks ignited in unison as the rocket found its target in the sky.

Khmer's Domination

The Khmer Empire ruled over the southern part of the Khorat Plateau from the ninth century A.D. until their defeat by the Siamese King Ramathibodi during the last half of the fourteenth century. From their Empire's center at Angkor on the Tonle Sap, a large inland lake along the middle reaches of the Mekong River, the Khmer built a series of stone temples along the southern flanks of the Mun River Valley to service Hindu pilgrims on their journey to visit the motherland in India. The largest of these temples at a length of over one kilometer, Khao Phra Viharn, situated in the Dong Rak mountains along the present day border between Kampuchea and Thailand in the Si Saket Province, one hundred kilometers southwest of Ubon, was built in the eleventh century under the authority of King Jayavarman II.

The enduring influence of the Khmer in the southern Khorat Plateau is evidenced by the fact that a stone stela erected at Tham Phet Thong, located between the Mun River and the Dong Rak mountains, during the reign of Bhavavarman in the last half of the sixth century A.D. commemorates his victory over the local people. An analysis of Bhavavarman II inscriptions on similar styled stela found in northwestern Kampuchea dated to the early seventh century makes it evident that he elevated himself in rank and status in competition with his foremost contemporary, Isanavarman. Three additional inscriptions found near the confluence of the Mun River with the Mekong River combine Sanskrit and archaic Khmer to record that Mahendravarman, the son of Viravarman, who was the younger brother of Bhavavarman, had celebrated a victory at the site. Like the later Khmer Emperors, the Varman overlords of the mid first millennium A.D. had maintained fortified royal centers in the middle reaches of the Mekong River at such sites as Isanapura, a rectangular shaped moated site located in the valley of the Stung Sen, a small tributary that empties into the Tonle Sap.

The literal translation of the Sanskrit term *varman* is armor but it can also be translated as “protected by.” As members of the cult of the *linga*, planting a phallic shaped stela signaled a Varman’s rightful claim to a region’s resources by sanction of his direct relationship with Siva, the Hindu god of fertility and change. “The duration of the political influence over the settlements in the Mun Valley is not known, but it is unlikely to have been long. It is only possible to speculate on the impact upon the occupants of the valley of an expedition under the great overlord Mahendravarman. There can be little doubt that the ruler seized booty and slaves which were one objective of such wars” (Higham 1989:280). The fact that competing Khmer Varman overlords and Khmer Emperors had been sending expeditions into the Mun River Valley for nearly a thousand years suggests to this author that their political influence upon the locals was likely to have been quite significant.

Funan’s Impact

Indeed, the Khmer Varman’s influence on the inhabitants of the Mun Valley can be traced back at least another five hundred years to the time of Funan, the first kingdom founded on the Southeast Asian Peninsula. “Sometime in the first millennium B.C., Malay sailors made one of the most significant discoveries in the history of navigation-how to ride the monsoons, the seasonal winds of Asia” (Shaffer 1996:14). By taking advantage of the seasonal wind pattern associated with the monsoons, Malay sailors were able to travel to destinations thousands of miles away with winds at their backs during both the journey to far away lands as well as the journey back home provided they were willing to spend the four intervening months waiting in port for the winds to change directions. The Funan ports such as Oc Eo near the mouth of the Mekong River provided just such a refuge along the maritime route that became established between China and India once the ability to ride the monsoon winds had been discovered. The area surrounding the Mekong Delta contained extensive flood plains capable of producing a highly dependable food supply for the large populations required to support such a far reaching enterprise. It was not until the first few centuries of the first millennium A.D. that the political structure necessary to organize the labor force required to reclaim the swamp land around the Delta began to emerge. This political structure was imported by the Indian traders and the *brahman* priests who accompanied them. " From the first century A.D, the delta of the Mekong appears to have sustained *mandalas* which were the foci of intensified centralization, incorporation of surrounding groups by force and the adoption of some Indian cultural traits" (Higham 1989:254).

The traditional history of the Funan area, as recorded by Chinese emissaries Kang Dai and Zhu Ying who visited the country in 250 AD, refers to a mythical ancestor known as Kaundinya, an Indian, who married a local princess. After attacking and conquering chiefs on the periphery of his domain, he installed his sons and grandsons in their place creating an hierarchical system of land management based upon the political theories set down by Kautilya of the Mauryan Empire in 325 B.C. Under this system, the state was comprised of seven heads: the king, his ministers, a territory, a fort, the treasury, an army and allies. The royal office entailed divine sanctions and the king possessed a divine nature. His duties were to control crime through the legal system, to protect the people he governed and to foster agriculture, industry and trade. The key to this system's success was the opening up of new land to settlement in order to create an ever expanding tax base. Kautilyan political theories precisely identified the required elements for statehood to emerge; a central authority, sustained by taxation and backed by coercion.

During the five centuries in which Funan flourished, great earth moving enterprises were undertaken by the rulers to reclaim the swampland areas that dominated the Mekong Delta. “This was probably accomplished by the excavation of drainage canals, which have survived to this day as a dominant feature of the archaeological landscape of the delta region” (Higham 1989:249). The rectangular shaped Oc Eo site lying behind five ramparts and four moats is bisected by a large canal that is part of an extensive canal system that linked it with the sea located several kilometers away. Excavations conducted by the Frenchman, Malleret at Oc Eo from 1959 to 1963 recovered two Roman gold medallions minted during the reign of Antoninus Pius (138-161 A.D.) and Marcus Aurelius (161-180 A.D.) in association with a Chinese bronze mirror belonging to the same period as the medallions. *Brahmi* script found on rings and seals at Oc Eo also belong to the late first and early second century A.D. “The quantity and range of goods which exchanged hands at Oc Eo exceeds by far that evidenced at any other site in Southeast Asia at that time. Clearly, this establishment was not only a port, but also a major manufacturing center which could dispose of sufficient labor to dig out the moats and erect centrally placed religious monuments” (Higham 1989:252).

Water Control Measures of the Khorat Plateau

It was not until A.D. Williams-Hunt’s 1950 analysis of aerial photographs taken during the Second World War that the significance of numerous circular shaped mounds, enclosed by moats and ramparted defenses, located throughout the Mun and Chi drainage basins was recognized. He concluded that several of these sites were considerably larger than the rest, which indicated to him that a possible hierarchy existed among the sites. According to Elizabeth Moore’s 1986 analysis of these features, settlements along small tributaries of the Mun and Chi Rivers had begun developing water control measures during the first half of the first millennium B.C., but major expansion of such earth moving enterprises did not appear until the latter half of the first millennium B.C. and the first half of the first millennium A.D. Similar oval moated sites are found on the margins of the Bangkok Plain, Northeastern Kampuchea and at the mouth of the Red River in the Bac Bo region of northern Vietnam.

Moated Sites of the Chi River Valley

The largest moated site on the Khorat Plateau, Muang Fa Daet, located in the middle reaches of the Chi River covers an area of 171 hectares. A 1991 excavation of the innermost mound of this multi-moated site “revealed three inhumation graves associated with an iron harpoon and socketed axe and glass, agate and carnelian beads, stratified over a layer of red-on-buff pottery which might relate to the early ceramics from Ban Chiang Hian” (Indrawooth as cited by Higham 1996:205). Ban Chiang Hian, located at the confluence of the Chi and Pao Rivers some thirty kilometers to the south of Muang Fa Daet, along with two of its smaller neighboring mounds, Ban Kho Noi and Non Noi, have been extensively excavated. “All three yielded a distinctive red-on-buff painted ware at the lowest occupation layers, but at Ban Kho Noi and Ban Chiang Hian, this was superceded, in the mid first millennium B.C., by a plainer ware. At this juncture, the excavators found the first evidence for iron and the water-buffalo” (Higham 1989:210).The site also yielded large concentrations of glass beads in the occupation layer containing the plainer wares. Ban Chiang Hian covering an area of about 38 hectares is surrounded by a double set of moats and the remains of a rampart with an adjoining reservoir. Chantaratiyakan’s 1984 analysis estimates that it would have taken five hundred well fed adults a year to complete the task of moving the hundred thousand cubic meters of soil to build the two moats and reservoir. The site is situated on a low terrace above the Chi’s flood plain immediately adjacent to a middle terrace, which allowed access to local iron ore and the necessary reserves of timber required for its smelting. Ban Chiang Hian was estimated to have supported a population of approximately two thousand. Another similarly large site covering approximately 38 hectares is Non Chai, located in the upper reaches of the Chi drainage system, was excavated by Pisit Charoenwongsa in 1978. This site sits upon a middle terrace located directly adjacent to extensive low terraces classified today as moderately suited for rice cultivation. Continuous occupation of the site is described in five phases dating from 400 B.C. through 200 A.D. Phases II and III dated between 300 and 200 B.C. yielded bronze and crucible fragments along with four glass beads. Clay moulds for casting bronze bracelets and bells were found in phase III through V contexts. Hundreds of glass beads appear during Phase IV dating between 200 to 1 B.C. Chantaratiyakan’s 1984 analysis indicates there are sharp differences in the form and finish of pottery at the site and contemporary wares at Ban Chiang Hian, but a few exotic sherds from the latter were found and probably represent imports. Middens yielded evidence of exploitation of an abundance of aquatic resources such as shellfish, crabs, frogs, turtle and fish along with domestic water-buffalo, cattle, pig and dog. In the small contemporaneous site of Ban Kok, located only six kilometers from Non Chai, Kijngam found pottery identical to that from Non Chai in association with iron.

Moated Sites of the Mun River Valley

A large moated site, Non Dua, is located sixty kilometers to the southeast of Ban Chiang Hian in the valley of the Lam Siao Yia, near the confluence of the Chi and Mun Rivers. This site is situated adjacent to an extensive deposit of rock salt known as Bo Phan Khan as well as to extensive low terrace soils suitable for rice cultivation. “Huge mounds which have accumulated all around Bo Phan Khan, points to the production on a scale far greater than would have been necessary to satisfy local demand alone. Industrial wares found during excavation of the moated site itself suggests that its occupants were concerned with the extraction of salt. Non Dua yielded a deep stratigraphic sequence, the initial phase of occupation being assigned to the period 500 to 1 B.C.” (Higham 1989:215). Pottery sherds found at Non Dua match both the form and elaborate decorative elements (geometric and curvilinear motifs) of contemporaneous ceramics at Ban Chiang Hian. Iron was found from the base of Non Dua.

At least twenty five moated sites comparable in size to Ban Chiang Hian are found in the upper and middle reaches of the Mun River. Excavations by Welsh at Ban Tamyae, located just a few kilometers from the Khmer stone temple at Phimai, document a pattern similar to that witnessed in the Chi valley. Bronze found at the lowest level of the site’s two and a half meter deep cultural stratigraphy is dated 1000 to 600 B.C. Both iron slag and the water-buffalo made their first appearance during the Prasat phase dated at 600 to 200 B.C. The nearby center of Phimai grew very large starting at the end of the Prasat phase and continuing through the Classic Phimai phase, lasting from 200 B.C. until 300 A.D., during which exotic glass items first appear. Less than twenty kilometers from Ban Tamyae is the moated site of Noen U-Loke, which has the distinction of having the most moats (five) of any prehistoric site in Southeast Asia. Moats are connected by canals to each of the two streams that flank the site. A cemetery, located at the center of the mound within the innermost moat, excavated by Wichakana in 1986 revealed three phases of inhumation graves. First phase graves cut into the substrate contained bronze and shell jewelry. Second phase graves contained bronze jewelry along with agate ornaments and small fragments of glass beads. Third phase graves contained pottery belonging to the Classic Phimai phase. “Third phase grave goods were richer and much more varied. Burial 2 was associated with a bronze headband, bronze earrings and bronze belt with a central buckle or plaque. Iron rings had been placed at the shoulder and in the groin area. A tanged iron knife was found at the left shoulder and a socketed axe had been placed at the left elbow. Similar iron tools were found with burial 1, a tanged sickle and knife found near the left hand. Numerous orange glass beads were found with burial 5” (Higham 1996:222). Evidence of local smelting activities exists in the form of several smelting furnaces located on the southeastern edge of the site. A kilometer away two high mounds suggest that salt extraction was a likely commercial activity as well.

Vallibhotama's extensive surveys of moated sites has led him to note that "They often provide surface evidence for iron smelting, and the further downstream, the more one encounters a novel burial rite, involving interment in lidded burial jars" (Vallibhotama as cited by Higham 1996:225). At Ban Don Phlong, a moated site located on the middle reaches of the Mun river, Nitta's excavations revealed seventeen well preserved clay smelting furnaces, one measuring 32 cm long and 25 cm wide. "The remains of tuyeres and much slag, taken in conjunction with the number and succession of furnaces on top of earlier ones, suggests that this area was set aside for iron smelting over a considerable time. Twelve radio carbon dates indicate that these phases belong from the fourth to second century B.C. An analysis of slag suggests that the abundant local laterite ores were used" (Nitta as cited by Higham 1996:225). Non Yang, located fifty kilometers downstream from Ban Don Phlong, reveals information about domestic structures. Nitta's excavations in 1989 and 1990 revealed "four structures, all built at ground level. They were constructed first by excavating a rectangular area for a foundation which comprised a row of circular timbers running across the short axis. The walls were built of clay over a timber frame, the interior surfaces being smoothed, the exterior being rougher. The carbonized support timbers indicate that they belong to the period 300-1 B.C. Baynard has suggested that they were rice stores" (Nitta as cited by Higham 1996:226). Non Yang contained evidence of interment in lidded burial jars, but very little human remains survived and no grave goods have been reported.

Possible Origins of the Iron Industry

The emergence of large population centers, secured by moats and defense ramparts, up and down the length of the Mun and Chi Rivers coincides with the sudden appearance of iron and glass products during the last half of the first millennium B.C. Both Chinese and Indian metallurgists had become proficient in working iron by 600 B.C. “Forging was the technique used in early Indian contexts, but in China there was an early development of iron-casting” (Li Chung as cited by Higham 1989:190). The first evidence of iron casting in Southeast Asia is found in the Bac Bo region of northern Viet Nam in late Dong Son contexts following the area’s incorporation into the Chinese Han Empire during the first century A.D. “Iron working in the rest of Southeast Asia was, according to available evidence, based on the small bloomery furnace to produce the iron, followed by forging” (Higham 1989:192). Along with importation of the Indian method of iron working and glass, agate and carnelian beads, the Kautilyan political doctrine of the fourth century B.C. Mauryan Empire is likely to have served as the impetus for the development of the first large commercial centers on the Khorat Plateau. Thus, instead of a mere thousand years, India’s political and economic influence on the inhabitants of the Khorat Plateau appears to have extended back for a period of at least two thousand years.

Ban Kan Luang

Ban Kan Luang, located on the outskirts of modern day Ubon, was excavated by the Thai Fine Arts Department in 1990 as part of the Pak Mun Dam Project funded by the Electric Generating Authority of Thailand. Nine large globular shaped clays jars with lids were found at a depth of one to two and a half meters below the original surface (figure A-2). The range of grave goods found inside the burial jars suggests an elite status of those interred. “A bronze figurine of a man standing 45 millimeters high, was found in one of the urns, the decorations on the body described as discoid motifs, being matched on the bracelets” (Woods and Perry as cited by Higham 1996:228). This object was of particular importance as “representations of human figures in bronze are virtually unknown in Khorat Plateau sites but are present in Bac Bo at the same juncture” (Higham 1996:229). The sizeof the figurine suggest that it may have served as a staff-head. The author was unable to find this figurine when he visited both the National Museum in Bangkok and the Provincial Museum in Ubon to photograph the site’s bronze artifacts. A large bronze spearhead may have possibly served as a ceremonial piece due to the two long and delicate points coming off the base of its blade, while a smaller tanged arrow head made of bronze was likely a weapon (figure A-3). Tiny bronze bells approximately ten millimeters in diameter were likely worn as items of personal adornment given their size (figure A-4). Bronze jewelry included profusely decorated bracelets and armlets (figure A-5). “These bronze ornaments were thinly casted (1.80-2.00 mm.) by lost wax technique into 8 types. Bronze ornaments such as bangles are similar to artifacts of Dongson culture (500 - 100 B.C.) which has its center in North Vietnam. Two types of bronze axes were found, large symmetrical axe with narrow mid waist type is commonly found in late prehistoric period of middle and lower Kong Basin and small boot shaped axe type is commonly found in Honghe river basin, Vietnam” (EGAT 1992:48). Actually four types of bronze axes, reported to be from the Ban Kan Luang site were photographed at the Provincial Museum in Ubon (figure A-6). Iron tools included axe heads and knives, while iron weapons included arrow heads and a sword. Included in the burial jars were stone anvils and polishing stones used in pottery making and unhusked grains of rice. Although no skeletal materials were found, organic residues found in the jars were high in calcium content suggesting cremation. In the fill surrounding the burial jars both iron slag and laterite ore were found, suggesting at least that local manufacture of the iron products was a possibility. As for the bronze objects found at Ban Kan Luang, no evidence was available to help determine their actual manufacturing methods. Information provided from the Pak Mun report concerning the boot shaped and symmetrical shaped axes suggests the possibility of their importation.

The Cham Influence

While uncommon on the Khorat Plateau and the remainder of Peninsular Southeast Asia, jar burials with cremated remains are found along the Viet Nam coast from the mouth of the Mekong to the southern boundaries of the Dong Son Culture in the Bac Bo region of northern Vietnam. The vessels are often large, covered with lids, aligned in rows, located approximately a meter below the present ground surface and contain a range of grave goods. The Hang Gon cemetery located near the mouth of the Mekong not only had these qualities in common with those at Ban Kan Luang but radiocarbon dates of 400 to 275 B.C. made them contemporaneous. The Thanh Duc site, near the village of Sa Huynh in central Vietnam contained 120 buried jars with cremated remains and a range of grave goods. On the west side of the Truong Son Cordillera near Ban Ang in modern day Laos, two groups of stone burial jars rest on the modern surface of the “Plain of Jars.” The smaller of the two groups sitting atop a centrally located hill have been found to contain a richer set of grave goods than the group occupying lower ground. As with the Hang Gon and Thanh Duc sites of Vietnam, these urns yielded glass and carnelian beads, bronze jewelry and iron knives, arrowheads and spearheads. Small bronze bells and a bronze figurine similar to those from the Ban Kan Luang site were found at the Ban Ang site, which has been dated at 300 B.C. Today, the central region of Vietnam known as "Cham" contains the only *Austronesian* speaking people on the Southeast Asian Peninsula. When the Chinese ushered in the historical age to this region in the first century A.D., they described the Cham burial rite as follows "the dead were placed in urns the quality of which varied with the status of the deceased incumbent" (Higham 1989:233).

The Cham's ancestral Sa Huynh Culture and its cemeteries appear to have arrived upon the shores of mainland Southeast Asia sometime in the last half of the first millennium B.C. "Cham, an Austronesian language has its closest parallels in Acehnese and Malayic languages spoken in southwest Borneo" (Higham 1996:304). It is likely these far ranging maritime people who transported the neighboring Dong Son Culture's hallmark bronze masterpieces, the large and intricately decorated kettle drums, throughout island Southeast Asia. Not only did the Cham continue to exchange trade with their motherland in the islands to the south, but it is likely the Cham who brought the knowledge of iron working and importation of glass and carnelian beads from India. As their style for treatment of the dead can be found at the mouth of the Mekong, in the highlands of Laos and at Ubon, it is also likely the Cham who brought the Kautilyan political doctrines that led to the centralization of authority and thus development of the first large commercial centers on the Khorat Plateau.

First versus Second Millennium B.C. Sites on the Khorat Plateau

Prior to the sudden appearance of iron and glass products during the second half of the first millennium B.C., settlements along the waterways of the Khorat Plateau remained smaller than five hectares in size with populations that did not exceed two hundred and fifty to three hundred individuals. As a population grew above this threshold level, group fission and movement to another location along the expansive river system was made possible due to the abundant availability of low terrace lands capable of supporting rice cultivation. While these autonomous settlements developed unique pottery styles which were rarely traded, evidence of exchange in marine shell and marble jewelry is present in mortuary contexts by the time bronze made its first appearance on the Khorat Plateau during the last half of the second millennium B.C.

The cemetery at Non Nok Tha excavated by Solheim in the mid 1960s, located on the upper reaches of the Chi River in the foothills of the Phetchabun Range, provides one of the best examples of the range of grave goods that were being offered both before and after the appearance of bronze. The seventeen earliest graves, dated at 2307 to 1310 B.C. by the AMS method using rice chaff temper found in the fabric of the pottery vessels that predominated the offerings, contained strings of shell disc beads, domestic cattle and pig bones and red pigment. Of the two hundred later graves, dated at 1320 to 1121 B.C. by the same method, only nine contained bronze items. “The sample is dominated by bracelets, 28 being found in five graves, two males, two females and one child. There were also five socketed axe heads, restricted to males. One male was also associated with a crucible and the sandstone mold for such an axe. We continue to find shell disc beads, cattle and pig limbs and crania and the use of red pigment" (Higham 1996:193).

The cemetery at Ban Chiang Hian, located near the confluence of the Chi and the Pao rivers provides an excellent example of the dramatic shift in exotic trade goods that was experienced in the middle reaches of the Chi valley at the beginning of the first millennium B.C.. Much distinct red on buff pottery is found in the basal one and a half meters of cultural deposits (layers nine through eleven) into which the earliest graves had been cut. "Grave goods included a heavy marble bracelet and shell disc beads. Radiocarbon dates from hearths about 80 centimeters above the substrate average 944-797 B.C. The pottery used at this site had little in common with that from Ban Chiang or Ban Na Di at the same period" (Higham 1996:204-205). Later period graves cut from layer six of the cultural deposits that contained most of the bronze fragments found at the site have been dated to the second half of the first millennium B.C.

The cemetery at Ban Na Di excavated by Higham and Kijngam in 1980 and 1981, located in the upper catchment's reaches of both the Songkhram and Pao Rivers, yielded sixty burials spanning much of the first millennium B.C. Although bronze was found in the fifteen phase 1a graves, it was limited to small wires used to repair two broken exotic stone bracelets. Shell beads as well as clay figurines of cattle, deer, elephants and humans were included as offerings along with pottery and the forelimbs of domestic cattle. Bronze became more frequent in the twenty one phase 1b graves but was limited to bracelets. "One woman had 19 bronze bracelets as well as a shell bracelet and over 100 shell beads" (Higham 1996:201). Pottery became more abundant and of a wider range. Along with the shell bracelets and beads, two complete cowry shells were included as grave goods with this group. In the twenty four phase 1c graves, only four included bronzes. These now include anklets and a coil along with the bracelets. Iron grave goods were more common than bronze and included a spearhead, a knife, a ring, four bracelets and a coil. In their site report, the excavators suggest that the mortuary phase 1 cemetery at Ban Na Di lasted from 900 to 100 B.C. "Pilditch has examined the bracelets from this site and has concluded that some were cast by the lost wax technique. No clay moulds have been found in the layers corresponding to the early cemetery phase, but many were found in layer five above. It is also likely that clay moulds were used by metal workers who repaired fractured stone bracelets with a wire-like casting through prepared holes" (Higham 1996:238). The phase 1 graves were cut into the lowest two meters of cultural deposits, labeled layers six through eight. Within layer eight, a bronze casting facility consisting of a clay lined furnace was found. "This took the form of a shallow bowl-furnace, ringed with bronze detritus and crucible fragments. Stone molds for casting axeheads and arrowheads have been found" (Higham 1996:238).

Not only did the range and quantity of grave goods increase over time, but evidence from two different clusters of burials interred during Ban Na Di's phase 1 cemetery suggests that one cluster was much richer in terms of exotic goods than the other. "Group A graves contained all the stone and trochus bracelets, all the clay animal and human figurines, the majority of shell disc beads and the iron artifacts. Twenty seven of the thirty two bronze items were found in Group A graves" (Higham 1996:203). A similar pattern of wealth being limited to a select few had been identified in the burial pattern at Non Nok Tha, which predated the cemetery at Ban Na Di by several hundred years. This suggests that control of exotic trade goods and perhaps knowledge of bronze technology was maintained by village clan leaders. The fact that both are linked in an enduring regional mortuary pattern further suggests that the bronze technology was imported along with the trade in exotic goods. The fact that evidence of metallurgical practices occurred at Non Nok Tha during the last few centuries of the second millennium B.C. necessitates that raw materials be available.

Copper Mining Activity

Large deposits of copper ores are available along the Mekong River in the Loei Province located in the northwestern corner of the Khorat Plateau. Excavations there at Pottery Flats near the Phu Lon mines by the Thailand Archaeometallurgy Project in 1984 and 1985 revealed “a single stratum comprised primarily of crushed sharn. A charcoal sample from the basal level of the stratum, presumably associated with some of the initial activity of the site, is dated to ca. 1750-1425 B.C.. Two other charcoal samples extracted from the ore crushing stratum yielded dates of 1000-420 B.C. and 790-275 B.C. Numerous rice chaff tempered crucible fragments, some with green dross adhering, a fragment of a sandstone mold, a fragment of a ceramic mold, large amounts of charcoal and some slag point to the presence of metal working activities at the Pottery Flats” (Natapintu 1988:113). Although, it is not made clear in the report, these industrial wastes evidently were dated to the ages given above for the ore crushing stratum rather than for the date given for the initial activity of the site. This interpretation is based on the statement “Clusters of tools and anvils in association with malachite bits and crushed sharn were found distributed on the surface of the stratum at various locations (Natapintu 1988:113).

Summary

The use of the extensive river systems as a means to transport exotic goods and ideas was a key prerequisite practice of the indigenous people that facilitated the spread of the metallurgical technologies throughout Peninsular Southeast Asia within the span of the first millennium B.C. Despite the availability of large quantities of copper, use of this material without being alloyed with tin appears to be totally absent from the region's archaeological record. This together with the fact that the bronze artifacts found at Bac Bo and the Khorat Plateau are the oldest of any in Peninsular and Island Southeast Asia supports the impression that the technology to produce these items came from an outside source that was most likely East Asia.

Unlike the East Asian archaeological record, that of Southeast Asia provides a greater amount of information on the techniques that had been employed to manufacture bronze objects. Data from a late second millennium B.C. cemetery at the Non Nok Tha site, located along the Phetchabun Range in the northwestern corner of the Khorat Plateau, indicate that a stone mould and a rice tempered clay crucible were found along with bronze grave goods that match exactly the design from the stone mould. Data from both a cemetery and occupational zone at the Ban Na Di site, located on the Sakhon Nakhon plate in the extreme northeastern corner of the Khorat Plateau, indicate that clay lined bowl furnaces, sandstone moulds, crucibles and clay moulds have been found in association with bronze grave goods dated to the first millennium B.C. These same types of tools are being used by smiths to manufacture bronze objects by the lost wax casting process on the Khorat Plateau at the present time. While this suggests the possibility that the lost wax casting process may have been the method by which bronze artifacts were being manufactured on the Khorat Plateau during the prehistoric period, the data from the smiths currently practicing this casting technique at Ban Pba Ao provides very specific information as to the exact types of cultural debris that should be found at a prehistoric site that had been practicing this technique.

CHAPTER V

BAN PBA AO

Having secured the necessary permits from the Research Council of Thailand early on Monday morning, June 2, the remainder of that day and part of the night was spent driving the six hundred and fifty kilometers from Bangkok to Ubon Ratchathani on narrow highways clogged with all kinds of vehicles including slow moving tractors and darting motorcycles. After a restful night's sleep at the home of my wife's Uncle Biak and Aunt Toi, who had introduced us to the smiths at Ban Pba Ao during the previous summer, we headed up the two lane paved road that leads to the northern regions of Isaan. After having passed by rice field after rice field, with only an occasional cluster of large trees surrounding a small rusted corrugated steel clad field house on stilts to break the monotonous plain, my wife and sole research assistant interpreted a road sign written in Thai at kilometer post 38 which indicated that we had arrived at the turn off to Ban Pba Ao. The concrete road to the village was so narrow that extreme caution had to be exercised when oncoming traffic approached to avoid falling the one and a half to two meters to the rice fields below. Slowing down to ensure our safety, we entered a time zone consisting of laborers planting rice sprigs one at a time in the fields that stretch as far as the eye could see on both sides of the road. As a result, twenty minutes were required to traverse the eleven kilometers from the main highway to the village.

Village Description

As we entered Ban Pba Ao, a large Wat or Buddhist temple, dominated the landscape with its towering roof lines and chedi or cremation chamber. Under the eaves of the temple roof were small bronze bells hanging at an interval of about one meter apart and completely surrounding the perimeter of the building. Near the top of a three story tower was a large bronze bell nearly a meter in height. In the story below that was a large bronze gong and in the lowest level was located a large wooden and skin drum. Traveling on the main road beyond the temple, we passed modest sized houses on stilts, in which women were seen weaving silk and cotton cloth on large looms in the open space located underneath several of these wooden structures. After crossing the one to two kilometers to get to the back portion of the village, we arrived at the research site marked by a small sign in English that read “Bronzewares.” Exiting the vehicle, we were greeted by numerous dogs and the strong stench of pig excrement. Although only nine in the morning, the heat and humidity was stifling making the barking dogs and the excrement smell seem all the more unpleasant. Traversing approximately forty to fifty meters down a narrow dirt alley between two small houses on stilts, we arrived at a one story concrete structure that serves as the smith’s shop.

Establishing Contact with the Smiths

Not having any contact with the smiths during the past year, we were very happy to find the business manager, Khun Sum lee, at the facility. Although, he informed us that the group’s leader, Khun Phryop, has passed away during the year, he also assured us that the family’s business continued to produce bronze products for local consumption and for purchase by the tourists that regularly visited the village. After providing a description of the research that we desired to undertake, Khun Sum lee agreed to produce seven to ten bronze bells for us over the course of the next week or so. We were asked to come back early the next morning as he would need a day to assemble the personnel required to complete our order. He also informed us that the village would be celebrating the Bun Bang Fai festival over the upcoming weekend and this could likely delay the completion of the bells. Before departing for the day, one of the smiths, Khun Boon mee, arrived at the shop. He expressed delight with the contract to produce the bells by smiling continuously throughout the fifteen minutes that was spent discussing the activities that would be occurring over the next week. He seemed to particularly enjoy the prospect of being photographed and having his picture shown to other researchers in the United States. He said that he would personally talk with the other smiths about our research and their need to sign informed consent releases. While Khun Sum lee was quite reserved and seemed to be all about business, Khun Boon mee's friendliness and enthusiasm served to put the research project on a much higher plain.

Day One Activities

At seven thirty the next morning, we arrived at the shop to find Khun Sum lee and four additional men, but no Khun Boon mee. Of these four men, Khun Boon tern, was the most talkative and provided the majority of the information obtained during the first work day. The other three men were quite shy and spoke very little. Their names were Khun Dumnern, Khun Kumpan and Khun Prasurn. Khun Sum lee indicated that Khun Boon mee had to attend to business associated with rice farming but would join us later in the week. I expressed concern over obtaining informed consent before proceeding on with my photography of the tasks to be undertaken for the day, but Khun Sum lee requested that I allow Khun Boon mee to take care of that upon his return. Khun Sum lee then departed for the remainder of the day. Day one included completion of the tasks involving construction of the inner moulds and manufacture of the wax string. The day was long, hot, smelly and conversation was limited to just the tasks at hand. Khun Boon mee's smiling face and pleasant demeanor was sorely missed. It was feared that the research would be lacking in depth due to the minimum of conversation that was generated the first workday. Even more disheartening was learning that the next day would need to be an off day in order to allow the clay moulds sufficient time to dry. We were asked to return on Friday morning around eight.

Day Three Activities

Arriving at the appointed time on Friday, we find all six smiths at the shop along with an elderly man, Khun Juntee, who happens to be blind. An inquiry into the cause of his blindness resulted in the researchers being told that he was born that way. We were told that he and another man, Khun Nu, that we would probably meet the next day, had been bronze smiths at Ban Pba Ao for many years. I expressed a desire to talk with Khun Juntee at length, but was asked by Khun Boon mee to wait until the next day as his help was needed to accomplish the amount of work that needed to get done that day. Honoring this request of Khun Boon mee proved to be quite helpful as extensive information was relayed by this very talkative man during the course of the day's activities. While he and Khun Juntee used a very crude wooden lathe device for over two hours to thoroughly smooth out the imperfections on the clay inner moulds, he provided invaluable insights into how this group of smiths was the last practicing members of the metallurgical tradition that had dominated village life in Ban Pba Ao for well over two centuries.

Khun Boon mee indicated that the seven smiths that we had been introduced to were all members of the same extended family and were the only ones currently practicing the lost wax technique in Ban Pba Ao and to his knowledge in all of the Ubon Ratchathani Province. He said they have ten to twelve young apprentices from their family that they are teaching this trade to in hopes of passing the knowledge on to yet another generation. He indicated that these apprentices are all males in their early teens as females have historically not participated in the trade. He expressed great pride in his trade, the male comradery enjoyed by the group and their efforts to deliberately keep mechanization down to the bare minimum in order to reflect traditional practices taught to them by the likes of men such as Khun Juntee, Khun Nu and the recent Khun Phryop. He indicated that when Khun Phryop passed away during the previous year, the group was fearful that his efforts to keep the trade alive might die. It was Khun Phryop who had brought their efforts to maintain traditional practices to the attention of the Tourism Authority of Thailand and who had secured funding from the Thai government to build their shop. He expressed the belief that the entire village had benefitted from the smiths efforts to bring tourists to Ban Pba Ao as more cloth production and sales was presently occurring than had been the case before Khun Phryop’s efforts. My research assistant surely did her part to support the cottage industry of cloth manufacturing during the two summers that she visited Ban Pba Ao. The fact that the ladies were so visible while they worked at their looms under their houses surely helped them to be noticed by those entering the village.

Day three, June 6, had been very productive on several fronts. Upon arrival, we found the inner moulds had thoroughly dried over the past two days as sunshine had prevailed and showers had been absent. The smiths were able to completely prepare the clay moulds, enclose them with a wax coating and apply the designs that would later represent the external surface of the bells. After coating these products and wax clappers with very fine sand, the smiths announced that they would be able to work for a couple of hours the next morning in order to complete the external clay moulds. The verbal exchange between the researchers and all the smiths had increased significantly under Khun Boon mee’s friendly influence. He gave the appearance of being the group’s leader even though he denied this. He insisted that they are an egalitarian group, each of which was capable of performing all the tasks associated with the lost wax process. He was the one, however, who has talked the group into coming back to the shop the next day despite it being the day of the Bun Bang Fai festival. We agreed to meet the next morning at seven.

Day Four Activities

Arriving at Ban Pba Ao on Saturday, June 7, the researchers found the otherwise sleepy village full of people out in the streets, vendors selling everything from gaudy plastic toys to fireworks and a large brightly colored rocket being slowly wheeled through the streets for all to admire and touch if they wish. The people were friendly and moved to the side to allow the researcher’s vehicle to pass through. At the shop, we not only found all seven of the smiths but Khun Nu as well. After proper introductions had been made, Khun Boom mee asked for the consent papers and got all the smiths to sign one. While the other four smiths combined clay and rice hulls together and coated the wax covered inner moulds with this mixture, Khun Boom mee and Khun Sum lee facilitated a lengthy discussion between Khun Nu, Khun Juntee and the researchers. Khun Nu did most of the talking as Khun Juntee remained quite shy and reserved. In fact, Khun Juntee was the only smith who did not sign a consent as Khun Boon mee said there was no reason for him to as he was blind.

Khun Nu indicated that he was presently seventy eight years old and that he no longer worked as a bronze smith due to his age. Khun Juntee indicated that he was only fifty eight and therefore was still young enough to do the work. Khun Nu indicated that he began his apprenticeship as a bronzesmith when he was fourteen, which was the ususal age at which someone joined the trade. He relayed that when he first began the trade, the entire village of Ban Pba Ao was engaged in the production of bronzewares. He indicated that each extended family, comprised of approximately forty to forty five people, ran their own shop. In the years just before World War II, he estimates that there were as many as fifty families engaged in the bronze trade. This would have made the village of Ban Pba Ao at least twice as large as it presently was. He reports that utilitarian wares such as dishes, utensils and cooking vessels were being made then in addition to bells and other ornaments. Their products were distributed throughout the Ubon Ratchatani Province and several surrounding provinces as well. He relayed that he learned the trade from his parents and grandparents as they in turn had done before him.

Khun Nu believed that it was around two hundred years ago during his great, great, great grandparents generation that the bronze tradition was brought to Ban Pba Ao. His great, great grandparents were the first generation to be born at the village. He interpreted the village's name as the following: Pba meant "left here" and Ao meant "uncle or brother in law." So, Ban Pba Ao was literally the "house or village of the brother in law that was left here." Khun Nu gave an account of a royal princess from Vientiane, Laos who came to the area about two hundred years ago looking for a place to establish her brother in law in the newly formed Ubon Ratchatani Province. Having decided upon the area that Ban Pba Ao now occupies, she left her brother in law and his family along with several Buddhist monks to begin a new settlement. It was the Buddhist monks who originally taught the villagers how to produce bronze wares by the lost wax technique. In fact, there were two temples originally in the village and each head monk or Khun Pah, was responsible for teaching the bronze trade to the villagers. It was not made clear why there were two temples previously and presently there was only one in the village. It could also not be made clear just exactly when there stopped being two temples in the village, but it appeared to have been sometime during Khun Nu's lifetime. He indicated that the monks had nothing to do with teaching him the bronze trade and that their involvement in the business had long since faded away. He reported that the remaining local temple had a museum of the various bronzewares produced over the years. Despite efforts the year before and the present year, direct access to this museum could not be obtained by the researchers.

Khun Nu described the bronze trade as dominating village life up to World War

II. He remembered that bronze ingots weighing around five kilograms were imported from Japan throughout his childhood years. This no longer became necessary during the war, as bronze was obtained from shell casings that could be found lying around everywhere after the Japanese invaded Thailand. This was the only reference made during our discussion to the Japanese and their occupation of Thailand, which Thai people do not wish to accentuate as Thailand literally translates into the "land of the free." He said that the beeswax had always been available commercially as long as he could remember. He relayed that the honeycomb they use had always come from local bee hives but the particular tree sap they use now had to be ordered from Daj Udom, located approximately fifty kilometers away as this tree no longer grew in their region. Evidence of extensive cutting of the local trees could be seen by their absence in the surrounding country side and by the fact that a tree trunk measuring two and a half meters in diameter was located along side the main road just as one entered the village. Although, the smiths continued to use recycled bronze in their productions, there did not seem to be any concern expressed by either Khun Nu or any of the other smiths for that matter about the loss of natural resources in their local community. Khun Nu ended his time with us by proudly stating that Khun Phryop had been his brother in law and that the village needed more leaders like him.

Day four proved to be very productive both in the history that was shared by Khun Nu and by the fact that the smiths were able to get all the moulds coated with a thick outer layer of clay and rice hulls. This mixture would require at least two days to fully dry and three if there was any rain. During the transfer of several of the moulds from one wooden platform to another, a smith dropped them to the ground. He calmly picked each of them up and placed them onto the wooden platform. Nothing was said by anyone about this mishap. This likely happened as the four smiths who had been doing this task had been drinking beer throughout the morning. This was the only time the researchers ever saw the smiths drink anything including water.

Apparently, drinking alcohol was a big part of the Bun Bang Fai festival as many people were found to be drinking on the streets as we left the village. Unlike when the researchers entered the village earlier that morning, upon leaving they were approached by several groups of men who had their hands out and were asking for money. As the first group indicated that the money was to be donated to the temple, the researcher gave them a couple of baht (five to ten cents). This proved helpful in getting these men to step back away from the vehicle, but it only served to encourage other groups of men who had witnessed the exchange to approach us with their hands out. We were able to make our way out of the village by rolling up our windows and totally ignoring anyone else that approached us. Once we turned off the small one lane concrete road that led to the bronzesmith’s shop, this bombardment of people asking for money ceased.

Having gained some sense of control over our destiny, we decided to stop and parked our vehicle near the large tree trunk laying along side the road near the entrance to the village. From the vantage point atop this fallen giant, we were able to observe the rocket that had been paraded through town all morning as it arrived back at the Wat’s main entrance gate. Out off a flurry of orange robed monks emerged an elderly monk with a small bronze bowl in his hands. He reached into the bowl and began to throw water from it onto the rocket that by now had been set into a nearly perpendicular position. In the sparkling azure sky above were several billowing cumulus clouds that a nearby villager reported was the rocket's target. No concern seemed to be expressed by those around us that the rocket could possibly fall back into the crowd of people who had come to see it launched. After being blessed by the elder monk's sprinkling of holy water, several of the town's elite including Khun Nu gave short speeches, the content of which could not be heard from our distance. After these dignitaries moved a safe distance back away from the rocket, a lone man approached and lit the rocket's fuse. At this same time, fireworks began to pop all around the village as young children made their contribution to the day's celebration. As the rocket soared upward and disappeared into one of the large cumulus clouds above, a loud jubilant cheer arose from the crowd along with another round of fireworks exploding. A nearby villager exclaimed, "We'll have some good rain now." Bun Bang Fai was clearly a fertility ritual by which the participation of all the people of the village helped to ensure bountiful rains during the upcoming wet season. Apparently, the rocket was intended to symbolically impregnate the cumulus cloud that it struck so as to ensure that many more clouds would be born in the near future.

Day Six Activities

Unfortunately for the villagers, it did not rain that day or the next. As a result, the external moulds were thoroughly dried when we returned to Ban Pha Ao at the appointed time of eight in the morning on Monday, June 9. Upon arrival, we find the smiths had already been heating bronze scraps in a crucible set inside a small bowl furnace since six that morning. Khun Boon mee and Khun Juntee were both absent. Khun Boon tern, Khun Dumnern, Khun Kumpan and Khun Prasurn were the smiths present when we arrived. Khun Sum lee arrived at the shop around ten. Khun Dumnern, who attended to the fire in the bowl furnace was more talkative than in previous days and provided extensive information about the furnace, crucible and bronze alloys. He said that at least four hours would be required to bring the bronze to its melting point using an open charcoal fire. He indicated that if the hand bellows, which were leaning nearby against the short wall separating the shop from the adjacent pig pens, were used rather than the electric leaf blower being used, it would take an additional hour or two to reach the needed temperature to melt the bronze. He did not ask which I prefer was used, but my suspicion was that if Khun Boon mee would have been there we would have seen the hand bellows in use at least part of the time.

Khun Dumnern indicated that a more sticky type of clay was used to manufacture both the crucible and the bowl furnace than was used to make the moulds as they must withstand intense heat for a prolonged period. Given the lighter color of the crucible and furnace, the clay used was probably kaolinite. Khun Dumnern indicated that more rice hulls was used as a tempering agent than with the moulds as this too helped to prevent cracking of these vessels. He indicated that both could be used three to five times before they became damaged and had to be discarded. There were previously used bowl furnaces, old crucibles, some with bronze still adhering to the inside walls, crucible pieces and numerous fragments of clay moulds with their characteristic design impressions lying haphazardly around the yard located next to the concrete shop.

Although these items were clearly in the way, no one tripped over any of them during the course of the busy day. These same waste items remained in their exact same locations on our final day at Ban Pba Ao. It was interesting to note that no type of safety device, such as goggles or gloves, was ever used. The preferred footwear was sandals and most wore short pants and short sleeve shirts. Despite this attire and absence of protective devices, none of the smiths were noticed to have any type of scars or skin damage of any kind. When asked how this was possible, Khun Dumnern simply replied that he never worried about it.

Khun Dumnern indicated that if lead was added to the bronze mixture, it would become liquified more rapidly and creates a better sound quality in the finished bell. He said they didn’t like to use lead, however, as not only did it dull the brilliance of the bronze but it increased the likelihood of cracks developing in the bells. He said that additional tin could be added to make the bronze a more golden color, but this too weakens the metal by making it too soft. The softer the metal the poorer the sound quality. He said that they produce a six to seven percent tin-bronze alloy to make their bells, as it has been found to produce both the best color and best sound.

Around nine, Khun Boon tern ignited the logs that had been placed under the open clay oven on which the clay molds had been placed upside down. The thirteen centimeter thick walls were reportedly made of the same gray clay and rice hull mixture that the moulds had been made from, with the exception that a higher percentage of rice hulls were used to increase its heat resistance. Khun Boon tern indicated that the height of the oven had been lowered by about fifty centimeters from what we had seen the previous week because the walls needed to be only the height of the product being manufactured. He said this allowed for easier removal of the moulds once properly heated. He indicated that the taller height of the previous oven was due to the larger size of the last bell that they had manufactured. The oven, unlike the furnace and crucibles, could be used just one or two times as the heat generated by the log fire causes it to crack and crumble to pieces. The heat from the blazing log fire also seemed to accentuate the smell of the pig excrement even greater.

When Khun Sum lee arrived around ten, he smiled at the orange glow coming off the molten bronze in the crucible but frowned when he found wax still dripping from the moulds situated over the open oven. He instructed Khun Boon tern to add more logs in order to increase the fire's temperature. Nearly another hour was required to properly cook all the wax out of the moulds. An unpleasant scowl could be seen on Khun Sum lee's face as the group waited around for the hour to pass. Only Khun Dumnern remained busy as he attended to the charcoal fire in the bowl furnace. He remained expressionless as he continued his hot task.

Around eleven, the molds were removed one at a time by Khun Prasurn with long handle tongs. It was Khun Boon tern rather than Khun Dumnern that ladled the molten bronze from the crucible and poured it onto the bowls located atop each of the moulds. Within a matter of just five minutes all twelve of the moulds had been filled. The remaining bronze in the crucible was poured directly by Khun Dumnern using the long handle tongs into an open clay tray to produce a small ingot. Apparently, it was the air that caused the open surface of the ingot to crust over giving it a distinctive oxe hide appearance, while the parts that came in contact with the clay tray were quite smooth.

After allowing the molds now full of bronze to cool for just five minutes, they were moved to a more open area out in the yard. Khun Boon tern immediately began removing the clay outer moulds as he reported that the bronze had already sufficiently hardened. Within a period of just ten minutes, he had managed to remove approximately ninety percent of the external moulds from all twelve of the bells. Only the clay around the handles remained after this initial cleaning by Khun Boon tern. The external molds were now lying on the ground in many broken pieces with the inside portion containing the impression being a very dark black color while the outside surface remained a light grayish brown.

Khun Prasurn and Khun Kumpan proceeded to remove the clay around the handles and the clay inner moulds, the latter of which proved to be a very difficult task. Nearly ten minutes was required to get the first inner mould to release its grip upon the bronze bell. As it came out of the bell, a very pungent odor similar to burning rope could be easily smelled from a distance of ten feet away. The inner moulds were very dark black and remained in a single piece in most instances. Khun Boon tern, who had been standing nearby, said the inner molds were hard to remove due to the bronze bells still being quite hot. He said that if the bells were allowed enough time to properly cool, that they would come out much easier. Khun Prasurn stated that he thought it was due to the fact that not enough manure had been added when the moulds were initially made.

As soon as the first bell was completely free of all its clay mould, Khun Prasurn began to strike it with a piece of scrap metal. He looked wearily over at Khun Kumpan as if something might be wrong. At this point, Khun Dumnern joined these two men to test the sound quality of each bell as it became free of its mould. When a metal spike was used to conduct his testing, a much crisper sound could be heard than was produced when the bell had been struck with the piece of scrap metal. Two bells with very large holes in their cylinder walls did not pass this sound test and were placed into a recycle bin. However, several bells with small holes in their sides managed to pass Khun Dumnern's sound test. When Khun Sum lee joined Khun Dumnern in testing the bells sound, a faint smile appeared on his face for the first time that day when he struck the largest of the bells with a metal rod. After striking the bell a few more times, he announced that the job has been a success. A cheer went up from the group at this juncture and the tension that had dominated the group's mood for the previous several hours seemed to disappear.

Khun Boon tern did not join in with the testing of the bells sound quality, but took the large bell which had passed inspection in order to prepare for the task of bringing its finish to a highly polished luster. Before being polished, the bronze bell was dull whitish gray in color. While the other men continued to repeatedly test the bells' sound, Khun Boon tern worked by himself over in the shop trying to make a wooden mould for the large bell to fit onto. He seemed disinterested in the pleasure being expressed over and over again by those ringing the new bells. Despite whittling at a wooden mould for nearly thirty minutes, he was unable to make it the exact shape necessary to secure the bronze bell onto it as the two pieces were spun on an electric lathe.

After Khun Dumnern relieved him of this task, the proper fitting wooden mould was produced within a matter of a few minutes. Khun Dumnern took over the task of polishing the ten bells that had passed the sound test. As several different size wooden moulds had to be created, the task required about an hour and a half for him to complete. Khun Prasurn and Khun Kumpan assisted Khun Dumnern by using a grinding wheel to perform the task of smoothing off the bottom and inside of each of the bells. Khun Boom tern and Khun Sum lee left the shop together as soon as the sound test was completed, which was just a little before one in the afternoon.

The rest of day six was spent watching the three remaining smiths work in total silence, broken only by the harsh sound being made by the constant grinding of metal. Throughout the days in which the smiths were observed, there had never been any type of music played in the background or any singing, whistling or humming done by any of them. By the end of the long, hot, smelly, and noisy day six at the shop, the smiths had produced ten highly polished bronze bells which had an exquisite sound to them when rung. Khun Dumnern requested that we return at eight the next morning to see how the clappers were attached to make the final product.

Day Seven Activities

We arrived at the shop at the appointed time on Tuesday, June 10, to find all seven of the smiths present. They were in a very jovial mood totally unlike the intense solemness displayed most of the previous day. Khun Boon mee was busy spreading a thin sheet of bronze out on the shop’s picnic table. After marking off a leaf design with a pen, he cut this shape out with a pair of tin snips. He indicated that this will serve as the wind fan that was to be attached to the clapper. As each fan was cut out, it was taken by one of the other smiths and attached to a clapper with a metal ring that was fashioned from a section of a coat hanger. Another piece of coat hanger was used to attach the clapper and wind fan to the bell through a small opening just below the handle. As the position at which the clapper hits the bell is critical, many adjustments were made to the length of this connection wire. The other smiths, with the exception of Khun Sum lee, worked on a bell until the proper striking position for the clapper was obtained. The sound of constantly ringing bells could be heard for over an hour during this particular task's completion. When a final position of the clapper would produce the desired sound for a bell, a cheer would go up in unison from the group.

The bells with small holes in their cylinder walls had been spot soldered by Khun Boon mee before we had arrived for the day. Once he had finished cutting out the number of wind fans needed, he turned his attention to polishing the three bells which had these repairs made to them. When he was asked why the holes had appeared in just five of the bells, he indicated that there were many possible reasons. When asked if it could have been caused by dropping the moulds before they had their outer clay skins applied, as had happened to several of the moulds on Saturday morning, Khun Boon mee smiled broadly and indicated that this was unlikely the cause for the imperfections. Once he had completely polished over the bells blemished areas, clappers and wind fans were attached to them as well. Only two of the three bells repaired with spot soldering were found to have a sound quality good enough to please the ear of Khun Sum lee. In addition, two of the bells that did not have any blemish holes in them did not pass the final sound test after a clapper and wind fan were attached. When asked what would happen to these defective bells, Khun Boon mee indicated that they would be melted back down during a future project. He proudly stated that their reputation as craftsmen must be preserved by selling only quality products. He indicated that the reason they never listen to music and try never to say anything discouraging while at the shop was that it might affect their ability to hear the bells properly.

A total of seven bells weighing 2.5 kilograms were manufactured during the seven day period the smiths were observed. Khun Sum lee figured the cost for the raw materials to be 950 baht and the daily wage for each worker was 210 bath, for a total labor cost of 4200 baht. As the exchange rate was 42 bahts per U.S. dollar, the labor fee amounted to one hundred dollars or five dollars per smith per day. The raw materials cost twenty two dollars and sixty two cents. When a twenty percent bonus was added to the final figure, the whole group of smiths posed for a photograph (figure A-7) and then helped to carry the bells out to our vehicle. Lots of hand shaking, smiles and “goodbyes” said in English by all the smiths made our departure into a fun rather than sad event.

CHAPTER VI

THE LOST WAX CASTING PROCESS

The following is an account of the “lost-wax” casting process as practiced by the bronze smiths of Ban Pba Ao during a seven day observation period conducted from June 4 through June 10, 2003 by the author, Daniel Eugene Everly, primary investigator and his assistant, Skulsri Suchataprakal Everly.

Constructing the Inner Moulds

Into a two liter ceramic mortar are placed one part fresh cow manure to two parts loamy sand, which are thoroughly mixed with a pestle for approximately five minutes. This mixture is rolled into a crude cylinder shape between the palms of the hands until the desired size of the product to be manufactured is obtained. A wooden dowel stick with a pointed end is inserted into the bottom of the cylinder and slowly pushed and twisted until it emerges through the other end about three centimeters above its top. The cylinder is then spun by one hand turning the dowel stick, while the other hand presses against the cylinder (figure A-8). The hand pressing against the cylinder is periodically moistened with water to help reduce friction. This continues for approximately a minute until the shape of the cylinder becomes visibly more symmetrical and the surface smooth to the touch. While care has been taken to form a cylindrical shaped mould, one end of the cylinder has been deliberately tapered into a bell shape. These moulds on a stick are then placed into a wooden jig where they are sun dried for two to three days. The shorter drying time is required when sunshine persists, while an additional day is required when overcast conditions prevail.

Once thoroughly dry, the moulds are worked further on a simple wooden lathe. While the lathe is slowly turned by one man pulling methodically back and forth on two connecting strings, another man presses gently against the rotating mould with a flat ended wooden stick (figure A-8). Starting at one end of the mould and working towards the other end, approximately three millimeters of the mould's external surface is removed. The mould is taken off the lathe and after being turned end for end is placed back on the lathe. It is then scraped again in the same manner described above removing another three or so millimeters off its surface. This alternating clockwise and counterclockwise scraping of the rotating mould produces an extremely symmetrical cylinder free of any visible deformities other than the tapered bell shape at one end. At approximately three centimeters from the bottom of the non-tapered end of the mould, a six millimeter wide strip of banana leaf is attached. Using a pointed wooden tool resembling a chop stick and the banana leaf strip as a guide, two grooves are cut into the mould about three to four millimeters deep to form a triangular shaped lip at what will eventually become the open end of the bell. The moulds are then slightly dampened by hand, covered completely with very fine sand and placed back on the wooden jig to dry.

Manufacturing the Wax

The wax is made from three ingredients consisting of a kilogram of honeycomb from the bee locally known as *sum ma rong*, a half kilogram of tree sap from a tree locally known as *thom tha khean*, which is used in sealing the hulls of small fishing boats, and three kilograms of commercial bees wax (figure A-9). The honeycomb helps give the mixture better form and the tree sap increases its stickiness. The tree sap is cut into small pieces and placed into a large metal wok, which is heated over a charcoal fire. Once this melts completely into a black liquid, the honeycomb is slowly added in small pieces until a desired texture is obtained. The hotter the ambient air temperature, the less honeycomb is needed to get this desired texture. The texture is right when a small wooden stick remains upright when inserted into the mixture. The commercial bees wax is added at this point and the ingredients are cooked over a red hot charcoal fire for approximately twenty minutes. Once a consistent burnt-orange color is achieved, the hot liquid is poured through a large piece of loosely woven cotton cloth into a plastic tub filled with water, where it is allowed to cool (figure A-9). When the wax is to be used, it is broken in large chunks, heated in the air over a charcoal fire and hand rolled into a thin rope approximately five to six millimeters in diameter. This wax rope is then inserted into a small opening located at one end of a wooden device, which when attached to a second wooded device that is pressed against the chest, extrudes a thin wax string from an even smaller opening at the opposite end of the wooden device (figure A-10). This one to two millimeter gauge wax string is caught in a flat wicker basket in a seemingly random fashion. Within a few minutes, the wax string is cool enough to be handled. As the wax string is removed from the tray, it unwinds from its random configuration without breaking or becoming snarled.

Wax Coating of the Inner Moulds

Picking up a hardened clay mould by the dowel stick with one hand, the wax string is pressed onto the mould with the other hand starting at its tapered end. As the dowel stick is slowly turned, the wax string is meticulously wound onto the mould's surface to ensure the string of each succeeding revolution makes contact with the string of the immediately preceding revolution. In this manner, the string is rolled onto the length of the clay cylinder stopping just slightly past where the three to four millimeter deep groove is located. Below the wax covered portion of the mould, a clay section about twenty five to twenty seven millimeters wide remains. At the stopping point, the wax string is then rolled in the opposite direction over the top of the previously applied wax string until two layers have been applied to the clay cylinder's surface (figure A-11). The wax covered cylinder is then held briefly over hot charcoal embers to cause the wax string to become slightly pliable. Turning the dowel stick with one hand, the thumb and index finger of the other hand are gently pressed against the softened wax until all the grooves between the wax string are no longer visible. Intermittent heating of the wax covered mould for a very brief moment occurs throughout the process of smoothing out the grooves to ensure the wax string remains adequately pliable (figure A-11).

Preparing the Wax Coated Moulds for the Appliqué

After allowing to harden for fifteen to twenty minutes, the wax coated mould is then placed back on the wooden lathe, where the two men work to smooth the wax surface as they had the clay surface before. Just as before, the entire surface of the wax covered cylinder is worked while it is first rotated clockwise then counterclockwise until all visible imperfections are removed. While continuing to slowly rotate the cylinder, two shallow grooves about eight to nine millimeters apart are cut into the wax surface near the top of the mould's tapered end with a hand held tool resembling a very small pizza cutter (figure A-12). Two additional shallow grooves about eight to nine millimeters apart are cut into the wax surface approximately five millimeters below the first set of grooves. A third set of shallow grooves are cut about fifteen millimeters from the non tapered end of the wax covered portion of the mould, but this time the grooves are placed directly next to one another and three rather than just two grooves are made in this particular location (figure A-12).

Applying the Iconography

Using a small tool cut out of water buffalo horn, a closed lotus blossom design is applied to the cylinder between the two lines previously cut into the top of the mould's tapered end (figure A-13). As the cylinder is slowly turned by the dowel with one hand, the flattened end of the tool made of horn is gently pressed into the wax with the other hand creating small impressions until an entire loop around the cylinder has been completed (figure A-13). Using a second tool cut out of water buffalo horn, a nested cube design is applied between the second set of grooves which are located twelve to thirteen millimeters below the first design band.

Removing the Wooden Dowel Handle

A hammer is gently struck against the pointed end of the wooden dowel stick that has been serving as a handling device for the clay moulds throughout the preceding steps. With just one or two strikes of the hammer, the dowel stick drops out the other end of the mould. Very fine sand is dropped into the opening created by the dowel stick's removal until all but the last three to four centimeter of the hole at the non-tapered end of the mould has been filled.

Creating Sprues and Handles

The non-tapered end of the cylinder is slightly heated over hot charcoal embers. One end of a tube of wax about twenty-five to thirty millimeters in length and five to six millimeters in diameter is slightly heated over the charcoal. The heated end of the tube is pressed against the heated end of the cylinder. Two such tubes are placed on the non-tapered end of the cylinder, resting against the exposed clay portion of the mould. The tapered end of the cylinder is slightly heated over the charcoal. After heating its ends, a semi circle tube of wax is added to the heated tapered end of the cylinder. Once in place, there is no further manipulation of these wax appendages or their intersections with the cylinder. The straight tube of wax will serve as a sprue or passageway through which molten wax and metal will later flow. The semi circle tube of wax will ultimately serve as the bell's handle.

Sealing the Wax Coated Moulds

Very fine sand is sieved several times through a small mesh cloth to remove any larger sand grains and other impurities. The sand used is from local termite mounds as these insects always produce just the right sized grain particles in the process of making their homes. Additionally, in the process of handling this sand, secretions from the termites make the sand particles become extremely sticky. This filtered sand is then thoroughly mixed with a small amount of water until an even creamy consistency is achieved. The sticky sand is first placed around the middle of the wax coated mould and in the handle's opening (figure A-14). It is then spread over the entire surface of the wax cylinder with the fingers of one hand, while the remaining clay surface of the mould is being held and rotated by the other hand. The sand is applied in ribbons until the entire mould's wax surface is covered to a depth of about four to five millimeters (figure A-14). The thickness of this sand coating is very important as the fact that every square millimeter of the wax surface must be covered. Failure to ensure complete coverage leads to small blemishes or holes in the final product. Once this step is completed, the mould is gently placed back onto a wooden dowel.

Drying the Sand Coated Moulds

The moulds are placed onto a flat wooden tray, with extreme care taken to avoid touching one mould against another. Touching one mould with another at this stage will lead to small blemishes or holes in the final product due to the inadvertent removal of some of the sticky sand coating. The moulds are allowed to dry out in the open air but completely out of the sunlight for a period of 18 to 24 hours.

Constructing the Clapper

A small amount of wax is made pliable by heating it over hot charcoal. It is then rolled between the palms of the hands until a tube approximately four to five centimeters long is produced. Small holes two to three millimeters in diameter are then punched through each end of this wax tube producing the mould for the bell's clapper. A small sprue is attached to one end of the wax clapper mould. The clapper moulds are also dusted in very fine sand and allowed to air dry for approximately one day.

Mixing the Tempered Clay for the External Moulds

Clay is mixed with thoroughly dried rice hulls at a ratio of two parts clay to one part rice hulls. The clay and rice are mixed together on a large cloth lying on the surface of the ground. The mixture is next kneaded by hand for three to four minutes to help ensure its proper consistency (figure A-15). The clay which has been dug from the ground right at the shop is reportedly very pure. It has been trucked in from a nearby village within the past year or so. Failure to ensure its purity will lead to larger holes in the final product caused by rocks exploding or wood disintegrating during the firing stage. However, there is no extra care taken when digging the clay from the ground to ensure the absence of impurities other than skimming off the top surface.

Constructing the External Clay Moulds

Holding the mould carefully by the dowel stick with one hand, the rice chaff tempered clay is placed around the middle portion of the mould with the fingers of the other hand. Clay is next added to the section of the mould between the handle and the middle section until the tapered end has been completely covered to a depth of fifteen to twenty millimeters. Holding the mould by its clay covered mid-section with one hand, the dowel stick is slowly pulled from the mould with the other hand. Clay is then added to the remainder of the cylinder, with extreme care being taken while applying the clay in the area where the sprues are located. After covering the sprues except for the last two to three millimeters of their tips, a shallow bowl is fashioned out of clay just above their location on the mould (figure A-15). Upon completion of the bowl, the ends of the wax sprues can just barely be discerned. This bowl will later serve as the funnel that will receive the molten metal as it is poured into the moulds. Onto the other end of the mould where the handle is located, a large circular lump of clay is attached which will serve as a base for the mould to stand on during later steps of the process. The moulds are a grayish brown color at this stage due to the clay's moisture content. A similar coating of the clappers with tempered clay is performed but a thickness of only five to ten millimeters is required to cover them. After each clapper is coated, it is hung on a small tree made of iron.

Drying the External Moulds

The completed moulds are set on their flattened bases onto a large wooden tray with their bowl ends facing upward. These moulds and the clapper moulds are allowed to air dry out of doors in the open for two to three days until they reach a light brown color. As with the inner moulds, if sunshine is the prevailing condition only two days are required to thoroughly dry the moulds. If rain or overcast skies occur during the drying period, the moulds are moved under a covered area and an additional day is required to ensure thorough drying of the moulds. Work is not done during the monsoon season as the humidity is just to high to permit the degree of drying required to harden the clay moulds.

Firing the Moulds

Once thoroughly dried, the clay moulds are placed upside down (bowl end) on a metal grate that is fifty five by fifty five centimeters square, which is located inside a clay oven that stands approximately seventy centimeters off the ground with walls that are approximately thirteen centimeters thick (figure A-16). Very large quantities of dry rice hulls are used to temper the clay from which the oven is constructed as it is expected to be used for just one or two firings. Two sides of the oven below grate level are open into which logs ten centimeters in diameter are placed. Similar sized logs are carefully stacked on top of the clay moulds as well so that dry wood is located both under and on top of the clay moulds. The iron tree containing the clappers is situated onto a base that is built into the oven's metal grate. The wood is then set afire (figure A-16). As the fire burns for the next two hours, the clay moulds become further hardened and the wax inside melts to drip out the channels created by the sprues. Additional fuel logs are added to keep the fire blazing throughout this two hour period.

Crucible's Construction

The crucible used to hold the molten bronze is made of clay that is reportedly even more pure than that which was used to make the outer moulds. As the crucible has a much lighter color to it than the dried clay moulds do, it is suspected that the clay from which it is made is kaolinite. A greater percentage of dry rice hulls has been used as a tempering agent in the construction of the crucible than was used in making the outer clay moulds (figure A-17). This higher percentage of rice hulls together with the use of a more plastic type of clay produces a much stronger vessel which can withstand the very high temperatures required to melt the bronze. The crucible is approximately twenty two to twenty four centimeters in height and approximately sixteen to seventeen centimeters in diameter, with one to one and a half centimeter thick walls (figure A-17). The crucible is cylindrical in shape with a nearly flat base.

Bowl Furnace Construction

The crucible is placed into a clay lined bowl furnace. This furnace is made of clay that is tempered with a high ratio of rice hulls similar to the crucible. The mouth of the furnace is approximately thirty four to thirty seven centimeters in diameter and twenty four centimeters in depth, all of which except for a eight to ten centimeter lip is situated below ground level. This lip of the furnace is approximately nineteen to twenty one centimeters in width, which is reportedly the thickness of the entire bowl furnace. Into one side of the lip is located a single tuyere, which has a diameter of four to five centimeters and is sixteen to eighteen centimeters long. The tuyere is lying flush along the surface of the ground and extends all the way through the lip into the furnace. The leaf blower used to provide the air blast does not actually come in contact with the tuyere, but is kept situated ten centimeters away due to the intense heat of the furnace.

Melting the Bronze

Small charcoal bricks are placed around the crucible until the entire volume of the furnace is filled to a level that nearly reaches the top lip of the crucible. The charcoal is set afire and charcoal is frequently added to maintain a level of this fuel near the crucible’s top lip. Bronze scraps, such as plumbing fixtures and fine metal shavings, are then placed into the crucible. Whenever charcoal gets into the crucible, it is blown out by the smith with a three foot long hallow wooden tube (figure A-18). To bring the fire to the temperature needed to melt the bronze, air is forced into the charcoal fire through the tuyere. Although hand manipulated bellows are available to provide the needed air blast, the smiths prefer to use an electric leaf blower for their convenience. This device is not run continuously. Instead, it is turned on for about five minutes at a time and then turned off for a few minutes whenever additional charcoal is added to the fire and impurities are blown out of the crucible. As the bronze becomes liquified, it is stirred with a long iron rod that has a plow shaped end to it (figure A-18). Molten bronze does not stick to the stirring rod due to iron’s higher melting point. The crucible is lifted a few centimeters every ten to fifteen minutes with iron thongs to allow charcoal bricks to fall underneath it, which ensures a consistent temperature is maintained around the entire vessel. The bronze is heated between three to four hours until a bright orange glow with brownish crust is achieved. If a more golden color for the bronze is desired, then a higher percentage of tin is added. However, too much tin weakens the bronze by making it too soft, which affects the sound quality of the bells. Lead can be added to increase the bell’s hardness and thus improve sound quality, but it darkens the bronze creating a less brilliant finish. The bronze used to make the project’s bells contained six to seven percent tin and no lead.

Pouring the Molten Bronze

Sand is spread out on the ground about a meter or so from the furnace until its a few centimeters thick. After the clay moulds have been fired for two full hours to ensure all the wax has melted out, they are lifted out of the oven with long iron thongs and placed upon their bases on the sand (figure A-19). Molten bronze is dipped from the crucible with a long handled iron ladle and poured into each mould. The bowl on top of the mould helps to funnel the bronze into the sprues. Bronze is added to one mould at a time until it no longer flows out of the bowl and down into the sprue (figure A-19). The mould is held securely in place on the sand during the pouring of the bronze with the same long handled thongs with which it was removed from the oven. Within a matter of five or six minutes all ten of the moulds have been filled with the molten bronze. To demonstrate the appearance of a product that is allowed to cool in contact with the air rather than inside a closed mould, the smiths pour molten bronze into a tempered clay mould that is the shape of a small sardine can (figure A-20). When cool, the top portion of this mould that was exposed to the air has the texture of a water buffalo’s hide (figure A-20). All remaining molten bronze is then poured directly onto the sand in globules about the size of a coin.

Removing the Bronze Product from the Clay Mould

Within five minutes, the bronze has cooled sufficiently to begin breaking apart the clay moulds (figure A-21). A large blade knife about thirty five centimeters in length is used by the smith to remove the external mould, with stabilization of the mould being provided by the smith’s use of a long wooden stick due to the moulds being to hot to handle by hand. A minute or two at the most is required to remove approximately ninety percent of the external clay from the bronze product. The bronze is not golden in color at this point but instead is a dull grayish white. Another minute or slightly more is required to remove the burnt clay around the bell’s handle, except for one bell which required approximately three minutes to work this portion of the clay loose. The sprue is removed with one accurate blow of the knife at the sprue’s juncture with the bottom of the bell.

As the bells are still too hot to be safely handled to remove the inner mould, they are allowed to cool for approximately twenty minutes. The bell is then picked up by its handle with pliers and the inner clay mould, which is nearly black in color, is stabbed at with a small pointed iron tool around its intersection with the bottom of the bell. After stabbing at the clay of the inner mould for a minute or two, the bell is then stuck with the flat side of the large bladed knife. If the inner clay mould fails to fall out in one piece, then additional stabbing at the portion remaining inside the bell continues until its removed (figure A-21). The removal of the inner moulds is more difficult than that of the external moulds as it requires up to five minutes to remove some of them from the bells. One smith indicates that this is due to the inside of the bells retaining heat for a longer period of time, while another smith indicates it is because not enough cow manure was used in its manufacture. It is likely that heat was the primary factor as the inner moulds produced a very pungent smell as they were being removed from the bells. Once all the inner moulds have been removed, the small pointed iron tool is used to remove the last of the external mould that remains inside the bell’s handle. This step has been saved for last as the handle is the most fragile part of the bell. Since over an hour has passed since the moulds were poured, sufficient cooling of the bronze has occurred to ensure its hardness to allow safe removal of the burnt clay from inside the bell’s handle. No bell was broken during the removal of the clay moulds, but three of the bells were found to have small holes in their cylinder walls. Two bells had such large holes in their sides that they were placed into a recycle bin along with the small ingot and coin sized globules that had been made with the left over bronze. While the smiths discussed what to do to repair the three bells with small holes, the principle investigator picked up one of these bells to discover that it was still too hot to be comfortably handled. When asked what had caused the holes in these bells, the smiths indicated that it was probably some imperfection present in the clay that had been used to make the external moulds.

Testing of the Bells’ Sound Quality

The smiths repeatedly struck the bells, including the three containing small holes, with bronze rods to test their sound quality (figure A-22). Two bells that had no visible imperfections were found to have an inferior sound and were placed into the recycle bin. Surprisingly all three of the bells with small holes passed this initial sound test. When a bell was first struck which produced the desired sound, the smith striking it would smile broadly. After numerous sound tests had been completed, the business manager, who had not participated in any way in the production of the bells, made a final sound test of his own. When he too smiled broadly after striking the largest bell with a bronze rod, a sound of cheer arose form the smiths as if announcing that the project had been a success.

Smoothing the Handle, Bottom and Inside of the Bells

Using a stone grinding wheel, the bottom of each bell is smoothed to remove the contact points where the sprues had been located and to create an extremely flat platform on which the bell could rest. The handle of each bell is smoothed in the same manner. A cone shaped grinding tool is used to smooth the inside of the handle and the inner portion of the bell. The grinding produces a very bright golden bronze finish to those sections worked, while the remainder of the bell remains the dull grayish white color.

Polishing the Bells

A wooden block is placed on a large lathe and worked with a iron chisel while the lathe is slowly turned until a bell is created that corresponds to the size of each bronze bell’s inside diameter. Once the proper form is achieved, the matching bronze bell is pressed onto the wooden mould. As the lathe is rapidly turned, an iron file is pressed against the bell’s surface which quickly creates a bright golden color (figure A-

23). A smaller tool resembling a long handled screw driver is used to polish those areas of the bell containing the design bands. The lathe is turned at a slower speed while these areas are being polished. The design bands are slightly worn down in the process of polishing but not enough to ruin their intricacy. The dull grayish white bell is transformed into a brilliant golden finish as a result of this polishing procedure (figure A-24). All dust that is produced from this task is collected and placed in the recycling bin.

Finishing the Bells

Using a very fine wire brush grinding wheel, a final polish is applied to each bell creating an extremely bright finish free of any visible imperfections. Throughout this finishing process and all previous steps, no smith ever wore goggles, gloves or other forms of personal protection. No smith had any large cuts on their hands, arms or face. The one man who had operated the hand driven lathe was blind, but his handicap was congenital and not related to trade.

Fashioning Wind Fans and Attaching the Clappers

The wind fans are cut from a thin sheet of bronze approximately a millimeter thick. A paper template is used to draw the heart shaped fans onto the bronze sheet. A collar is added to the top of the heart shape, which is used to increase the strength of the fan. Tin snips are used to cut the fan from the bronze sheet. The collar is folded over onto itself twice to produce a tube of metal into which a small hole is punched. One end of the bronze clapper is attached to the wind fan with a closed loop of metal wire. The other end of the clapper is attached to the bronze bell with a loop of wire that has two legs extending beyond the loop (figure A-25). The length of these legs is adjusted until the clapper strikes the lip that was created on the inside of the non tapered end of the bell.

Final Testing of Sound Quality

While several smiths were adding the clappers and wind fans to the bells, the other smiths and the business manager continued to test the sound quality of the bells for a period that lasted nearly an hour. This task seemed to be of extreme importance as an additional bell was removed from the final cut as it did not produce a satisfactory sound to several of the smiths. This bell was one of the three that had been soldered to repair the small holes in their cylinder walls. In the end, seven bells were completed for the commissioned project.

CHAPTER VII

SUMMARY OF FINDINGS

My observations of the Ban Pba Ao smiths' performance of the lost wax casting process revealed several relevant facts which should prove useful in the interpretation of Peninsular Southeast Asia's archaeological record. The vast majority of the findings concern the discarded wastes associated with the manufacturing process rather than with the bronze objects that were actually produced. This indicates that it would serve researchers well to focus more closely on a site's stratigraphy rather than relying on the bronze artifacts to help determine the type of processes that might have been used to manufacture them. In this chapter, I discuss a total of nine findings from current smithing activities that should provide valuable insights into understanding the activities of metallurgists during Southeast Asia's prehistoric period.

Wax Residues

When the moulds were place upside down and heated over a blazing wood fire, the smith's objective was clearly to run all the wax out of the moulds through the sprue vents. Wood continued to be added for a period of two hours to maintain leaping flames beneath the moulds, until no further wax could be seen dripping from them. This casting technique was aptly named the "lost wax" process due to this particular step. Wax from the clay moulds did not accumulate as it dripped into the wood fire's intense heat. The wax disintegrated into the surrounding air just as wax from a candle does when it is burnt. As a result, any wax residue that might be found in a prehistoric site's charcoal hearths should not be assumed to reflect activities associated with the lost wax casting process. When a ten power jeweler’s optic loop was used to inspect the grayish white bronze pieces immediately after their removal from the clay moulds, no evidence of wax residue was seen in any of the numerous grooved designs located on the bells outer surface. Inspection of the Ban Kan Luang bronze artifacts with this same jeweler’s loop did not reveal any signs of wax residue in these objects either. This finding suggests that should wax be found in the grooves of a bronze artifact, it does not necessarily indicate that the object was produced by the lost wax process.

Bronze Residues

The Ban Pba Ao smiths demonstrated considerable care in their conservation efforts while working with bronze metal. The pouring of molten metal was done over a thin sheet of sand to aide in the clean up of any bronze that was spilled during the filing of the moulds. A small oval shaped mould had been made to collect the molten bronze that was left over after all the bell moulds had been filled. The last small amount of molten bronze that remained in the crucible, after most of the left over had been emptied into the small oval mould, was poured deliberately onto the sand to create coin size globules. All the bronze which had been spilled was collected, cleaned of sand particles and returned to a recycling bin for later use. When the sprues had been removed from the bells and clappers, they were collected and returned to the recycling bin. Recycling of metal scraps was so meticulous that even the dust accumulated during the polishing step was collected and returned to the recycling bin. Given the smiths degree of reverence shown for the bronze waste produced during the manufacturing process at Ban Pba Ao, it is unlikely that a significant amount of bronze residue would be found in any site at which indigenous metallurgical practices had occurred during the prehistoric period.

Ingot Casting

The ingot produced by the smiths with the left over molten bronze had a distinctive “oxe hide” or dark blistered appearance to the side which was not contained by the oval clay mould. In contrast, the sides of the ingot, which had come into contact with the clay mould were smooth and burnt red in color. The “oxe hide” surface apparently is produced as a result of the molten bronze’s exposure to the oxygen in the air. A similarly textured surface was seen on the top of the molten bronze in the crucible during the hours that it was being heated, but its color was bright orange rather than black. An ingot found in the archaeological record containing such an “oxe hide” surface should be considered evidence of rapid cooling in an oxygen rich atmosphere following its casting into an open mould. The moulds for ingots should be more likely found in the archaeological record than should actual ingots given the extreme reverence and conservation shown bronze by the smiths at Ban Pba Ao.

Wood Smithing Tools

As many of the implements used by the smiths were made of wood, such as the lathe, dowel sticks, smoothing tools, chest press, etc., their disintegration would likely be quite rapid in the humid tropical climate of Southeast Asia. Any wood tool that managed to survive from the prehistoric period would likely have so little of its form left in tact that its function would be impossible to discern.

Bowl Furnaces and Crucibles

The bowl furnaces and crucibles made of kaolinite clay with rice hull tempering were strengthened considerably by the length of time that intense heat was used to bring the bronze that was cooked in them to its melting point. This strengthening effect was multiplied by the fact that these particular items were used three to five times before they become too damaged to be used any further. The increased strength of the fabric together with the thickness of the vessel walls would cause both bowl furnaces and crucibles to survive depositional forces over a considerable period of time. However, as bowl furnaces and crucibles were used to smelt copper ores and to melt metals for other types of casting activities, their presence in the archaeological record does not necessarily indicate that the lost wax process was being used.

Clay Ovens

The clay oven on which the moulds were heated was used only once or twice before being dismantled and discarded. As the clay contained a high percentage of rice hulls as a tempering agent, waste from discarded ovens may produce visible lenses in a site’s stratigraphic sequence particularly if repeatedly deposited in the same location. However, as kilns used today in the Ubon Ratchathani Province to produce ceramic wares and dome ovens used to produce charcoal are made of the same clay with rice hull tempered consistency, they too would produce the same types of depositional lenses when discarded. Therefore, the presence of such clay lenses containing high percentages of rice hulls in an archaeological site would not necessarily mean that metallurgy had been practiced there.

External Clay Moulds

The external clay moulds were thoroughly dried by the sun for two days before they were placed in the clay oven. The moulds became hardened further by the fire's heat as the wax inside them was melted out. As the moulds were heated for only two hours over the fire, they did not become as hard as clay does when it is fired for the many more hours that is needed to produce ceramic wares. As a result, the fragile external moulds will become crushed from trampling by humans and other animals or by the accumulated weight of the refuse pile into which they may become deposited. After exposed to years of tropical moisture, the outside five or six millimeters of these fragile external moulds will disintegrate into a formless matrix of clay particles mixed with rice hulls.

In contrast, the inside portion of the external clay mould which made direct contact with the molten bronze became blackened and was strengthened considerably from the metal's very intense heat. Although this vitrified inner section of the external clay mould was only about one or two millimeters thick at the most, it was obviously much stronger than the thicker outside section of the external mould. Whereas, the outside section could be scratched with a fingernail, the inner section could not. Therefore, even though their thinness exposed them to the same likelihood of being crushed under the various depositional pressures as the outside sections of the external moulds were, their increased strength would cause them to maintain some degree of structural integrity when exposed to tropical moisture. As these blackened inner fragments of the clay moulds contain the design impressions from the wax engravings against which they were moulded, they would represent quite tangible evidence of the use of the lost wax casting process should they be found in an archaeological site (figure

A-26). However, because of the effects of depositional forces, any fragments of the blackened inner section of the external mould would likely be quite small. Because of their small size, identification of any design impression that might be located on a given fragment would likely be quite difficult to identify by the naked eye. Their black color could cause these mould fragments to be mistaken as charcoal fragments. A key to differentiating these blackened mould fragments from charcoal fragments would be the fact that mould fragments would very likely always be found in the clay and rice hull matrix that is created from the disintegration of the more fragile section of the external moulds. The accumulation of discarded external moulds in a refuse pile would create a clay and rice hull lense, which could contain these signature mould fragments of the lost wax process.

Internal Moulds

The internal mould that formed the inside of the bell was much harder after being fired than was the external mould. The manure tempering agent and the loamy sand that were used to make the internal mould became thoroughly cooked during the two hours that the moulds were heated over the open fire. The smell of cooking manure was still evident as the smiths pried the last of the freshly poured bronze bells free from their internal moulds nearly an hour after they had been taken off the oven rack. The retention of heat inside the internal mould was maintained by the bronze bell that surrounded all but one of its ends. The sections of the inner mould which came in direct contact with the molten bronze became vitrified and blackened just as those same sections of the external mould had. This resulted in the formation of very hard globular shaped objects that were black all over except for one end which was a light tan in color. Due to their increased hardness and basic globular shape, inner moulds should be much more likely than external moulds to withstand the forces of deposition. The presence of blackened globular shaped earth with one much lighter end found in a matrix of clay and rice hulls could serve as a signal to pay closer attention to any small black clay chips that might also happen to be found in the same matrix. The association of clay, rice hulls, blackened globules of earth and blackened fragments of vitrified clay with design imprints found together in the lense of a stratigraphic sequence would provide the most tangible evidence possible that the lost wax casting process had been used to produce any bronze objects that might be found in that lense or other stratigraphic levels dated to the same age as these waste byproducts.

Smithing Traditions

Although not as tangible as the other items listed above, the delicacy, color, sound quality and other aesthetic aspects of bronze objects may reflect the traditions and perhaps to some extent the philosophies of the smiths that produced them or the people who actually used them. In the case with the smiths at Ban Pha Ao, the sound quality of the bells they produced was of more importance than was the physical quality of the bronze color or the intricacy of the design impressions. Several bells that had no physical imperfections to their appearance were rejected and sent to the recycling bin due to their poor sound quality, while bells that had unsightly repairs made to them by soldering the small holes that had somehow developed in them managed to make the final cut because they produced a tone that was pleasing to smiths' discerning ear. A more golden color could have been produced by adding a greater percentage of tin to the bronze, but this was deliberately avoided by the smiths because adding more tin would have lessen the sound quality of the bells by giving them a distinctly tinny sound. To the smiths at Ban Pba Ao, the sound of their products was the ultimate measure of their products' quality. They had developed a very high level of self respect for their skill in producing pleasantly sounding bells rather than for the production of objects that had a beautiful color or intricate design. Their commitment to this standard of quality became crystal clear as the smiths spent the last hour of our time with them repeatedly ringing the bells to ensure they were sending out nothing less than their best from their shop to whomever was lucky enough to hear the seven bells they had made for my wife and I. Therefore, the meaning of quality for any given artifact can be quite different for those who originally made or used the object than it might be for those who attempt to interpret its purpose and value at a later time.

Conclusion

Stratigraphic sequences in Southeast Asia are typically quite difficult to delineate due to the nearly complete absence of definitive horizons in the very deep oxisol soils that dominate. In contrast, any archaeological site found in fluvial deposits provides a tremendous opportunity to use stratigraphy as an interpretative tool due to the seasonal flooding that occurs during the annual monsoon season. Not only does the flood plain receive the sediment load of this regularly occurring flood event, but quite often so do the first terraces, which exactly was where the vast majority of Peninsular Southeast Asia's prehistoric settlements were located. In the matter of a relatively short number of years, a thick layer of sediment could effectively preserve habitation and occupational zones associated with any given site located on such a first terrace.

It is as a result of such frequent flooding, that rice farming has been such a profitable enterprise in the tropics of Southeast Asia for many millennium. The nutritional needs of young rice sprigs are not that demanding as all that they need to grow comes primarily from the blue green algae that flourish in the perpetually wet fields. Therefore, contrary to what might otherwise be expected, well developed paleosols will not be found in those locations where rice farming had been continuously practiced for many generations. The norm then for the stratigraphy in which most Peninsular Southeast Asian prehistoric sites will be found is thick fluvial sediments, whose rapid deposition should help to secure the cultural deposits within them while at the same time preclude the development of paleosols which could serve as diagnostic time markers within a given sequence.

My observations at Ban Pba Ao revealed that the yard in which the actual metallurgical activities associated with the lost wax casting process occurred was not cleaned up in any noticeable way after a day of heavy use. Hearths, bowl furnaces, crucibles and mould fragments laid strewn haphazardly about the yard with no concern shown by the smiths about the dangers which these objects potentially represented. Years of these types of accumulated materials being discarded in one location would eventually create a thick mound of cultural deposits. Following abandonment of such a site located on a first terrace near a small stream, rapid capping of the mound by the fluvial sediments of repeated over the bank flooding events would likely occur in a relatively short period of time. Preservation of the cultural materials within the mound could be quite good depending upon how quickly the site became enveloped in fluvial deposits. Flooding from the occasional typhoon that strikes Peninsular Southeast Asia could result in a site being completed capped by fluvial sediments during a single wet season.

Charcoal hearths have been used to obtain radiocarbon dates for many of the prehistoric archaeological sites excavated in Peninsular Southeast Asia. Hearths found in the same stratigraphic level as crucibles and stone moulds have been used to provide dates that enable sites to be assigned to a particular metal age. As fluvial sediments located along the Khorat Plateau’s waterways are primarily well sorted sands, the identification of cultural remains within a clay lense in a site’s stratigraphy should signal the possible presence of an occupational zone of some type. The findings from this study suggest that when hearths are located in the same stratigraphic level as crucibles or bowl furnaces, greater attention to the type of matrix that they are found in may identify the presence of the signature clay, rice hull and vitrified mould traces that in combination would clearly indicate that the lost wax casting process had been the specific technique employed at the site. Even if the immediate matrix surrounding a crucible or bowl furnace does not contain these three signature materials, lateral investigation of the same stratigraphic level may reveal that they are located close by.

Bronze objects continue to be deliberately sought during most excavations conducted in Southeast Asia in order to help establish cultural boundaries, trade routes, symbols of hierarchal ranking and other supposed realities of past societies. If more attention were paid to the specific stratigraphic sequences from which these objects are extracted, it is this paper’s conclusion that very useful information could be determined about the actual processes which had been used to manufacture them. Such factual data may prove very helpful in illuminating the answers to some of the theoretical issues listed above.

REFERENCES CITED

Brandes, E.A. (editor)
1983 *Smithells Metal Reference Book.* Butterworths, London.

Chandler, H.
1998 *Metallurgy for the Non-Metallurgist.* ASM International, Materials Park, Ohio.

Charles, J.A.
1985 Determinative Mineralogy and the Origins of Metallurgy. In *British Museum Occasional Paper No. 48, Furnaces and Smelting-Technology in Antiquity,* edited by P.T. Craddock and M.J. Hughes, pp. 21-28. British Museum Publications, London.

Electric Generating Authority of Thailand (EGAT)
1992 *Archaeology of Pak Mun Dam.* Thai Fine Arts Department Publications, Bangkok.

Hegde, K.T.M. and J.E. Ericson
1985 Ancient Indian Copper Smelting Furnaces. In *British Museum Occasional Paper No. 48, Furnaces and Smelting-Technology in Antiquity,* edited by P.T. Craddock and M.J. Hughes, pp. 59-69. British Museum Publications, London.

Higham, C.
1989 *The Archaeology of Mainland Southeast Asia.* Cambridge University Press, Cambridge.

Higham, C.
1996 *The Bronze Age of Southeast Asia.* Cambridge University Press, Cambridge.

Higham, C. and R. Thosarat
1998 *Prehistoric Thailand, From Early Settlement to Sukhothai.* River Books, Bangkok.

Marechal, J.R.
1985 Methods of Roasting and the Furnaces Used. Translated by P.T. Craddock, In *British Museum Occasional Paper No. 48, Furnaces and Smelting-Technology in Antiquity,* edited by P.T. Craddock and M.J. Hughes, pp. 29-41, British Museum Publications, London.

Natapintu, S.
1988 Current Research on Ancient Copper-Based Metallurgy in Thailand. In

Prehistoric Studies: The Stone Age and Metal Ages in Thailand, edited by P. Charoenwongsa and B. Bronson, pp. 107-124. Thai Antiquity Working Group, Bangkok.

Needham, J.
1974 *Science and Civilization in China.* vol. 5. Cambridge University Press, Cambridge.

Nutt, M.C.
1968 *Principles of Modern Metallurgy.* Charles E. Merrill, Columbus, Ohio.

Ronan, C.A. and J. Needham
1978 *The Shorter Science and Civilization in China.* vol. 1. Cambridge University Press, Cambridge.

Rothenberg, B.
1985 Copper Smelting Furnaces in the Arabah, Israel: The Archeological Evidence. In *British Museum Occasional Paper No. 48, Furnaces and Smelting-Technology in Antiquity,* edited by P.T. Craddock and M.J. Hughes, pp. 123-150. British Museum Publications, London.

Rowe, J.H.
1962 Stages and Periods in Archaeological Interpretations. *Southwestern Journal of Anthropology,* 18(1): 40-51.

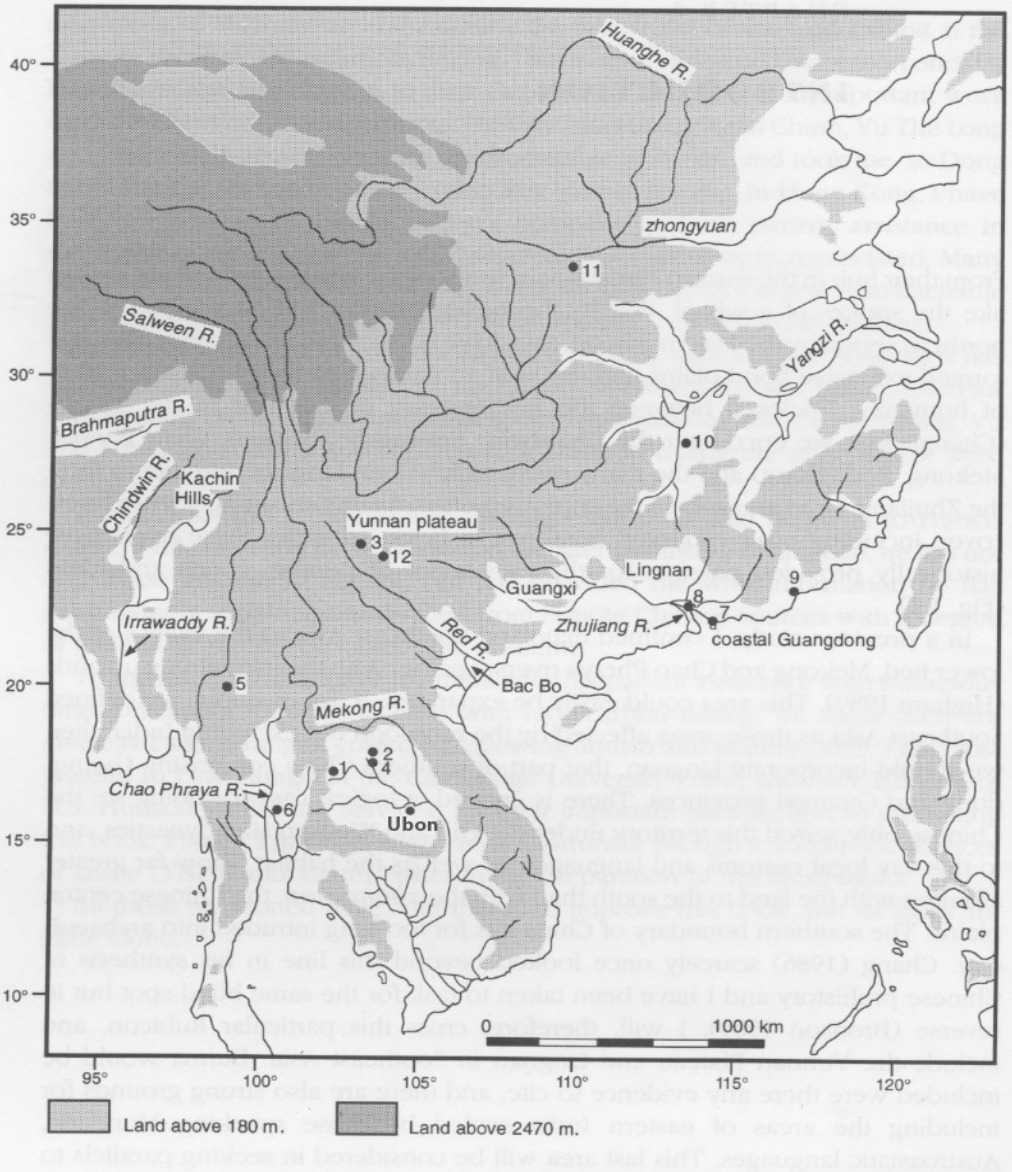
Shaffer, L.N.
1996 *Maritime Southeast Asia to 1500.* M.E. Sharpe, Armonk, New York.

Tylecote, R.F.
1992 *A History of Metallurgy, Second Edition.* The Institute of Materials, Book Number 498, London.

Tylecote, R.F. and J.F. Merkel
1985 Experimental Smelting Techniques: Achievements and Future. In *British Museum Occasional Paper No. 48, Furnaces and Smelting-Technology in Antiquity,* edited by P.T. Craddock and M.J. Hughes, pp. 3-17. British Museum Publications, London.

Zwicker, U., H. Greiner, K-H. Hofmann, and M. Reithinger
1985 Smelting, Refining and Alloying of Copper and Copper Alloys in Crucible Furnaces during Prehistoric up to Roman Times. In *British Museum Occasional Paper No. 48, Furnaces and Smelting-Technology in Antiquity,* edited by P.T. Craddock and M.J. Hughes, pp. 103-115. British Museum Publications, London.

APPENDIX A



1.1 Southeast and East Asia, showing the principal rivers and locations of places mentioned in this chapter, together with climate stations considered below. **1.** Non Nok Tha. **2.** Ban Chiang. **3.** Wanjiaba. **4.** Ban Na Di. **5.** Spirit Cave. **6.** Chansen. **7.** Hong Kong. **8.** Guangzhou. **9.** Shantou. **10.** Changsha. **11.** Xian. **12.** Kunming.

Figure A-1. Map of Eastern Asia (Higham 1996:2).

Figure A-2. Lidded burial jars at the Ban Kan Luang site.

Figure A-3. Bronze spearhead and arrowhead from the Ban Kan Luang site.

Figure A-4. Bronze bells from the Ban Kan Luang site.

Figure A-5. Bronze bracelets and armlets from the Ban Kan Luang site.

Figure A-6. Bronze axes from the Ban Kan Luang site.

Figure A-7. The bronze smiths at Ban Pba Ao. Pictured left to right bottom row: Khun Juntee, Khun Sum lee, Khun Boon tern, and Khun Prasurn. Pictured left to right top row: Khun Boon mee, Khun Dumnern and Khun Kumpan.

Figure A-8. Constructing the inner mould.

Figure A-9. Manufacturing the wax.

Figure A-10. Making wax string with a chest press.

Figure A-11. Wax coating of the inner moulds.

Figure A-12. Preparing the wax coated moulds for the appliqué.

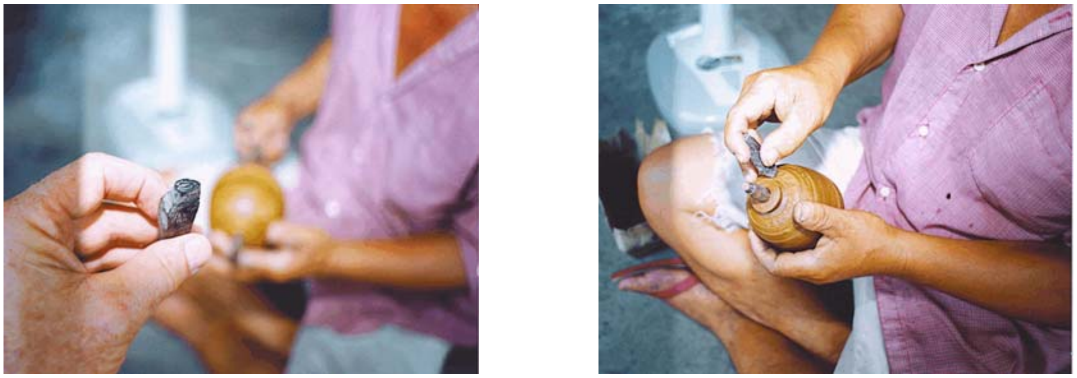


Figure A-13. Applying the iconography.

Figure A-14. Sealing the wax coated moulds.

Figure A-15. Applying the external moulds.

Figure A-16. Melting the wax from the moulds.

Figure A-17. Rice chaff tempered crucibles.

Figure A-18. Heating the bronze in a crucible set inside a bowl furnace.

Figure A-19. Pouring the bronze into the moulds.

Figure A-20. Making an oxe hide bronze ingot.

Figure A-21. Removing the bronze bells from the clay moulds.

Figure A-22. Testing the bells sound quality.

Figure A-23. Polishing the bell on a lathe.

Figure A-24. Comparison of a polished and unpolished bronze bell.

Figure A-25. Attaching the clapper and wind fan to the bell.

Figure A-26. Vitrified inner portion of external clay mould.

VITA

DANIEL EUGENE EVERLY

Permanent Address:

1121 Anderson Lane

Brenham, Texas, 77833

Education:

Master of Arts - Anthropology

Texas A&M University

December 2004

Master of Arts - Behavioral Science

University of Houston, Clear Lake

May 1978

Bachelor of Science - Psychology

May 1974

Work Experience:

Associate Clinical Psychologist

Texas Department of Aging and Disabilities

4001 Highway 36 South

Brenham, Texas, 77833

July 1982 through December 2004

Spouse: Skulsri Suchataprakal Everly