The Techniques of the Early Thai Metalsmith

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and ROBERT MADDIN

Archaeological research in Thailand during the past decade has produced evidence of an early bronze metallurgical tradition, the beginnings of which may date to the fourth millennium B.C. Excavations at Non Nok Tha and Ban Chiang have uncovered a wealth of metal artifacts, including ornaments and weapons, and material related to metalworking, such as moulds and crucibles. Since the controversy regarding certain aspects of Southeast Asian metal production is considerable, archaeologists and metallurgists must collaborate to study and assess the metal objects and methods of manufacture in order to reconstruct early Thai metallurgy in the most orderly fashion. We are grateful to Wilhelm G. Solheim, II, the excavator of Non Nok Tha, and Pisit Charoenwongsa and Chester Gorman, co-directors of the Ban Chiang excavations, for the opportunity to study their collections of metal artifacts. The dates cited are those of the excavators.

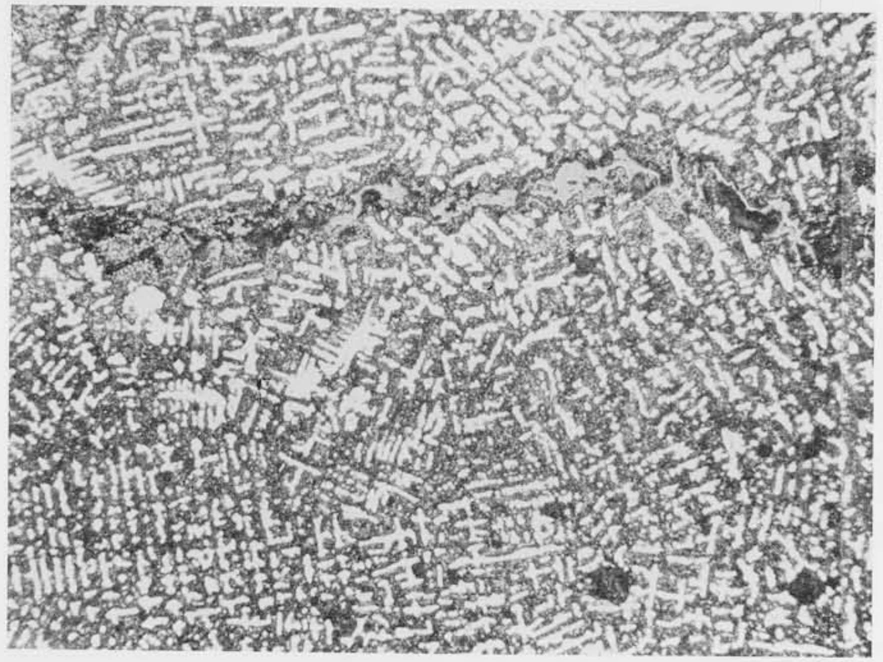
The report presented here must be regarded as preliminary to the complete analysis of a representative sampling of the over 800 metal objects found at Ban Chiang and supplementary to the work of Cyril S. Smith on bronzes from Non Nok Tha and several other sites in northeastern Thailand. This discussion is based on metallographic and electron microscopic examination of nineteen specimens from Ban Chiang and nine from Non Nok Tha. The objects studied from both sites include spearheads, bracelets, a necklace, a ring, an anklet, a piece of bar stock and several unidentified fragments. All of the samples exhibited some degree of corrosion; nine from Ban Chiang and one from Non Nok Tha were totally corroded and could not be studied productively. Almost all of the viable samples were etched with ferric chloride, several with ammonium peroxide and one with a high tin content with ammonium persulfate.

Because of the extent of corrosion which in many cases had penetrated beyond the surface of the object into the body of the metal, accurate elemental analysis was difficult. Elemental analysis by x-ray fluorescence was performed by Gary Carriveau of the Metropolitan Museum of Art at Brookhaven National Laboratories. Several objects which have not yet been examined metallographically are being analysed by wet chemical methods by W.T. Chase of the Freer Gallery of Art. In general, it seems safe to say that most of the specimens studied are made of normal tin bronze containing about 10% tin with copper and some impurities as the remainder. The earliest known metal object from Ban Chiang, a spearhead dated to about 3600 B.C., was determined by optical emission spectrography to have 1.3% tin; since this method of analysis has an inherent 10-20% factor of error and readings on tin in the equipment in our laboratory are consistently low, the tin content of the spearhead could be as much as three times greater than the analysis indicates. Although it is possible that the amount of tin detected in the spearhead exceeds that indicated by the analysis, it does not allow us to state with certainty that this is a deliberate alloy. An intentional bronze is usually defined as one with 2% or more tin. In order to substantiate the claim that the spearhead is one of the oldest bronzes known from anywhere in the world, the tin content must be determined by a more sensitive technique than optical emission spectrography. The spearhead will be submitted for a second analysis to obtain confirmation or denial of the first analysis.

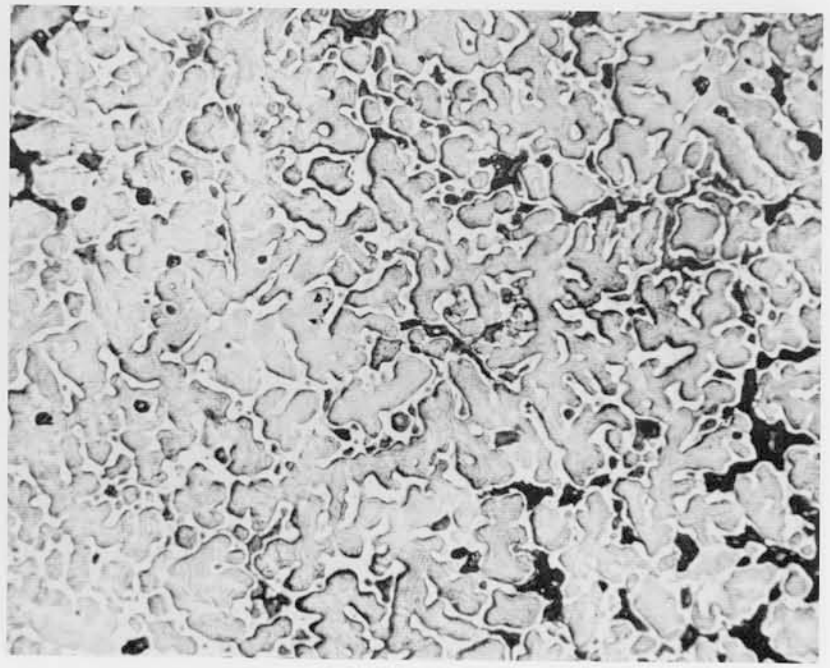
Ban Chiang 584, a ring dated to the period 500-0 B.C., contains zinc as the major alloying element in the amount of 10% or more. Since this is the only brass piece studied so far, we hesitate to call it a deliberate brass and suggest that it results from misidentified or mixed ores. Eight of the twenty-five specimens contain lead in concentrations of 1-5.5%. Lead improves the castability of bronze and so may have been added deliberately. Lead ores do, however, occur in the area of the copper sources closest to Ban Chiang and lead may result in the finished objects because of its geological co-occurrence with the copper. A relatively high lead content has no relationship to the date or type of object, although it is possible that some of the analyses have been affected by the tendency of lead to segregate.

Copper sulphide and copper iron sulphide particles were observed with the energy dispersive spectrometer associated with the scanning electron microscope; sulphur is not detectable spectrographically. The presence of sulphide particles sometimes gives clues about the type of copper ores from which the objects were made, either weathered oxide or carbonate ores like azurite and malachite, or mined and roasted sulphide ores like chalcocite and chalcopyrite. Evidence to date suggests that the Ban Chiang and Non Nok Tha artifacts were made either from well weathered ores or from well roasted sulphide ores. Roasting, the process by which chunks of sulphide ore are heated in the open air so that the sulphur will pass off as a gas, is necessary because the presence of combined sulphur makes copper difficult to smelt. Through the action of air and water over a period of thousands of years, exposed sulphide ores will also be converted to oxides and carbonates so the type of ore used may not be clear in some cases. When identification of ore types cannot be positively made, recourse can be made to the ores available in the area. Little is known about the types of copper ores used by ancient Thai metalworkers, so no definite determinations can yet be made. William Schauffler of the Ban Chiang expedition has surveyed northeastern Thailand in an attempt to locate mining and smelting sites. The results of Mr. Schauffler's research and future programs of inquiry should help identify the ore sources and the types of ores which would have been available in ancient times.

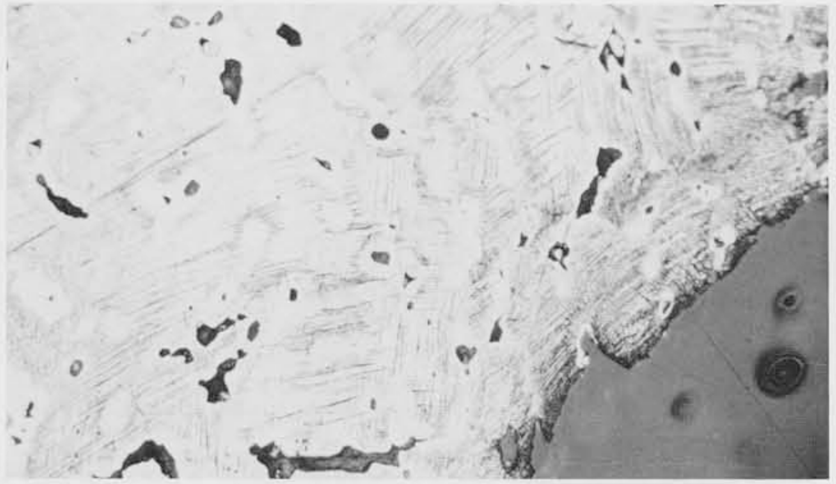
Most of the objects were cast, as revealed by the dendritic form of the microstructures. Dendrites, so designated because of their treelike shape, are formed when an alloy is cast. When an alloy solidifies, the first solid component has a different chemical content than the average content of the liquid from which it solidifies, forming the cores of the dendrites and enriching the remaining liquid in the other component. Continuation of the solidification process results in dendrites which have gradually differing chemical compositions. In the alloy of copper and tin, the first particles to solidify are rich in copper while the last are rich in tin. If the differing composition of each section of the structure is visible in the optical microscope, the structure is referred to as cored and results from a rapid solidification of the liquid which does not permit diffusion of the various types of atoms to form a more homogeneous structure.



1
Ban Chiang 676, a flat fragment, Phase III, 500-0 B.C. This optical micrograph shows the dendritic or treelike structure characteristic of cast alloys. X 100. Etched with ferric chloride.



2
Non Nok Tha NP 270, fragment, Layer 13, A.D. 200. The optical micrograph shows the cored dendritic structure characteristic of relatively rapid cooling of an alloy, in this object probably a 10% tin bronze. X 50. Etched with ferric chloride.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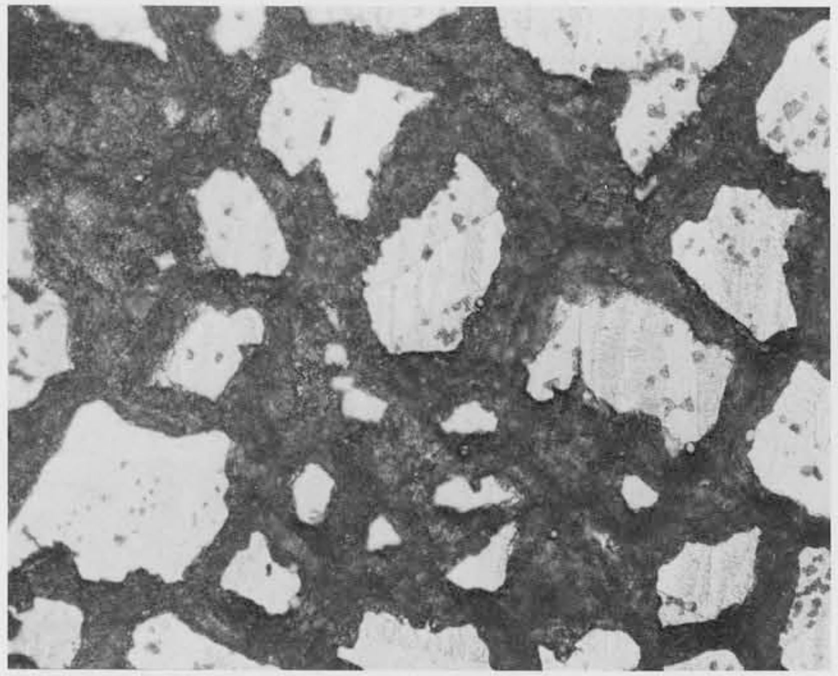
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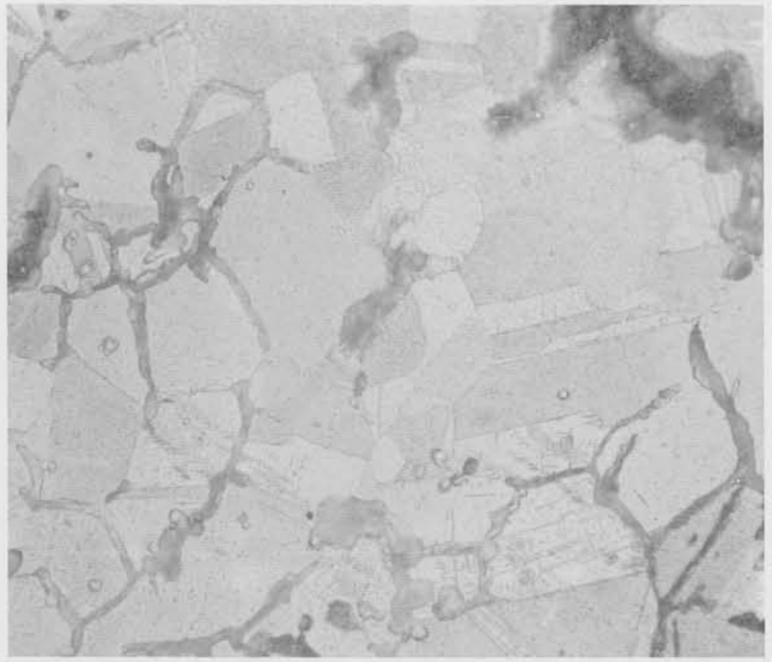
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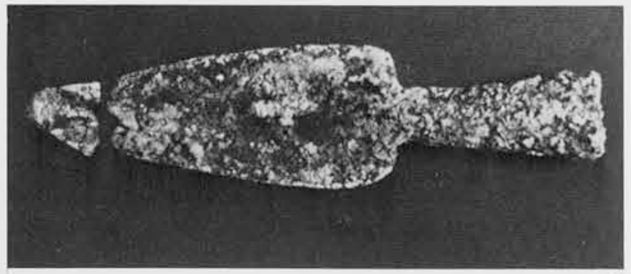
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1
Non Nok Tha NP 286, fragment, Layer 9, A.D. 1100. The black striae in this optical micrograph are strain markings which show up because a chemical has preferentially etched areas strained by deformation. X 200. Etched with ferric chloride.

2
Ban Chiang 1115, rectangular bracelet, Phase I, before 3000 B.C. The parallel bands of this optical micrograph are called annealing twins and are characteristic of a coldworked and recrystallized 10% tin bronze structure. Dark matrix is corrosion. X 500. Etched with ferric chloride.

The dendritic structure is visible if the object is not extensively worked or reheated. Both of these operations can be detected by metallographic examination. The scars produced by cold hammering appear as black striae known as strain markings. Sometimes coldworking was the smith's final procedure. The internal strain created by cold deformation was in some objects partially or completely eliminated by reheating the object to an elevated temperature below the melting point, a process known as annealing. In order for the strain to be completely relieved, it was necessary to reheat the object to the recrystallization temperature, a temperature above which the atoms in a strained configuration rearrange themselves into a strain-free configuration. The recrystallization temperature varies in each object according to the nature of the metal or alloy and the impurities it contains. The ancient smith did not know the temperature which each object required for recrystallization or even how to judge when a certain temperature had been attained, so he could not tell if an object had been completely annealed. He did know that after reheating an object which could not be further coldworked without cracking, he could continue coldworking. Therefore it is not surprising that in some ancient bronze objects the modern metallographer will see incompletely recrystallized structures. Such recrystallization in metals and alloys as a 10% tin bronze can be detected by the presence of "annealing twins" in the microstructure.


5

3, 4
Ban Chiang ES 2834, bronze socketed spearhead, 15.5 cm. long, Phase I, c 3600 B.C. Note annealing twins in the upper portion of the optical micrograph and strain markings in the lower portion. X 500. Etched with ammonium peroxide.

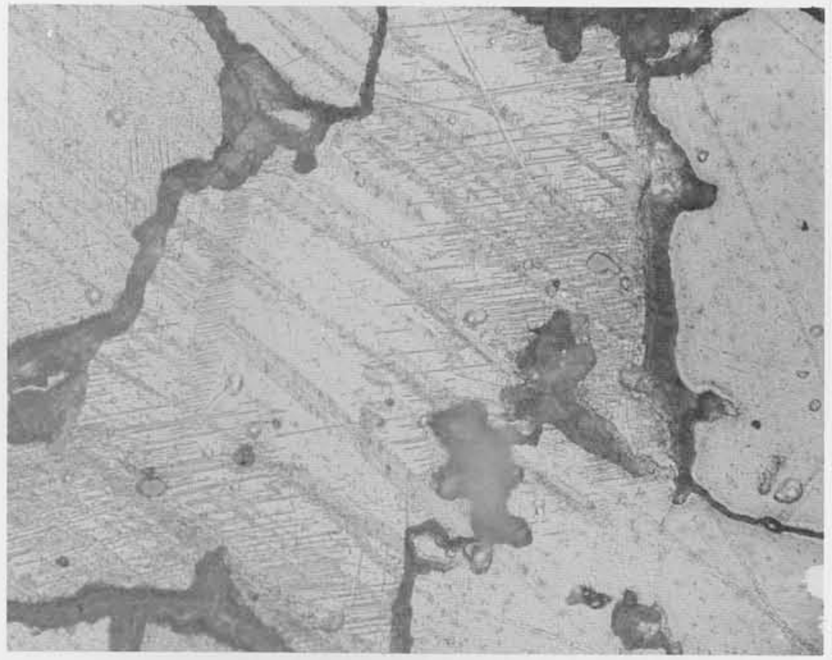
5
Ban Chiang ES 2834. Radiograph.

6
Ban Chiang ES 2834. Strain markings show in untwinned grains indicating that recrystallization has not occurred in this area. X 500. Etched with ammonium peroxide.

7
Ban Chiang ES 584, brass ring, Phase III, 500-0 B.C. The optical micrograph shows the structure of cast, worked and recrystallized brass. X 500. Etched with ferric chloride.

These annealing twins appear as parallel bands of different shading within a single grain and arise when reheating relieves the strain of coldworking by allowing a crystallographic reorganization of the distorted positions of the atoms in the structure. The changed crystallographic orientation of the planes is visible because the light in an optical microscope reflects differently from the various planes, producing the effect of shaded bands.

This metallurgical lesson provides the basis for understanding the sophistication which the Thai metalsmith had achieved by 3600 B.C. The earliest piece excavated at Ban Chiang, a spearhead, shows that casting, coldworking and annealing to produce recrystallization and possibly alloying were part of the smith's repertoire at that time. This spearhead was most likely cast as a unit in a bivalve mould with a core inserted during casting to shape the socket, since radiography showed that the metal of the socket and blade is continuous with no seam. Some shaping of the object was however done after casting. Annealing twins and strain markings are visible in the microstructure, which suggests that recrystallization was not complete since the remaining strain markings occur in untwinned grains. Corrosion has attacked the grain boundaries (see the darker areas in photos 6 and 7 on this page). The brass ring from Ban Chiang, made at least 3000 years after the spearhead, shows that alloying, casting, coldworking and annealing remained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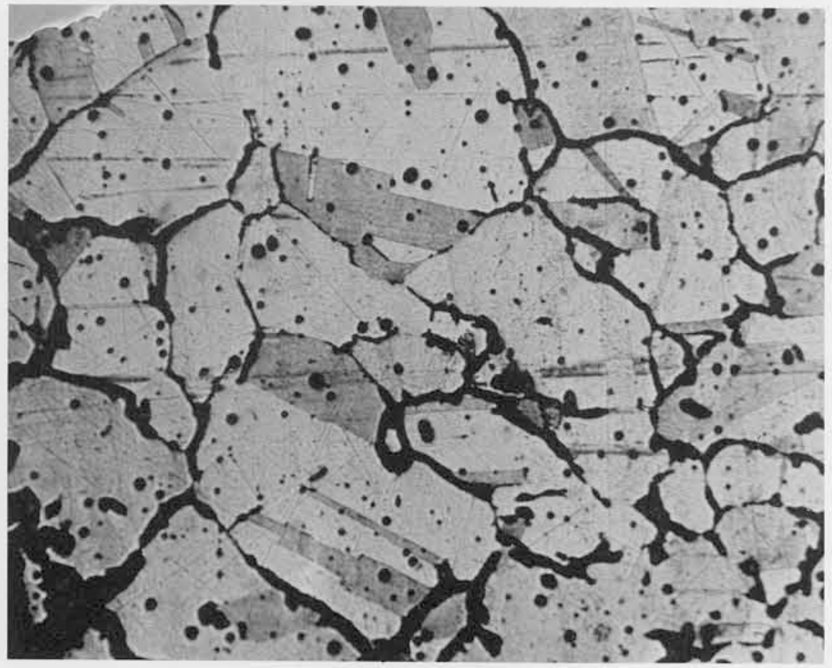
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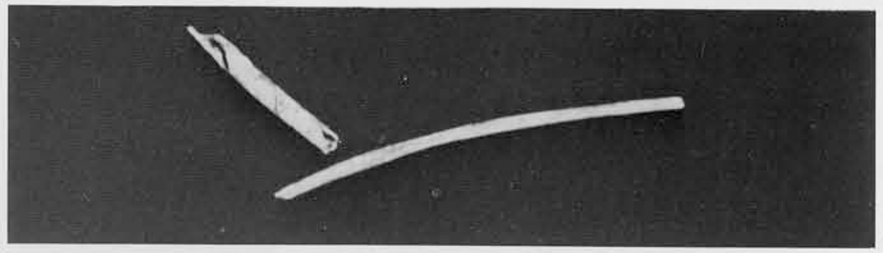
among the smith's techniques.

1
Ban Chiang 918, components of necklace. The larger is approximately 2.5 cm. long. Phase III, 500-0 B.C.



2
Ban Chiang 918, microphotograph taken under polarized light. This optical micrograph shows a structure which has undergone a solid state, martensitic-type transformation, which occurs in hotworked and quenched bronzes with a 22-25% tin content. X 500. Etched with ammonium persulfate.

From an aesthetic and technological point of view, the most interesting piece in the collection is a necklace from Ban Chiang, which probably dates to 500-0 B.C. It is made of a number of thin rods, some straight and some helical. The helical pieces are flat strips twisted into shape; all of those examined by us were completely corroded but had the typical green appearance of normal bronze. Because of the corrosion, they could not be measured to determine whether they were made by wrapping flat strips around a mandrel. The straight rods are healthy metal and have a veneer of dark grey to black corrosion. They are approximately square in cross section. It is the straight rods which indicate a high level of technological skill. Difficulty in etching with ferric chloride, a standard etchant used on bronze, and subsequent electron microscopic analysis indicated that they have a greater tin content than the other specimens examined. The energy dispersive spectrometer associated with the scanning electron microscope also revealed that the rods had a greater tin content than other Thai bronzes studied, but this analysis had to be dealt with cautiously since quantitative statements cannot be made on the basis of energy dispersive spectrometer readings. Optical examination under polarized light revealed that the matrix had undergone a solid state or martensitic transformation, one which occurs, relative to temperature, when the arrangement of atoms in a solid material changes, thus producing a second solid state form of the material more stable at a lower temperature. The effects of this solid state transformation cannot be detected in the scanning electron microscope since the transformed matrix is of unified chemical composition. Solid state transformations such as observed in the Ban Chiang necklace take place in a β-phase bronze which contains 22% to 25% tin. Bronze with such a high tin content is too hard to be coldworked into the delicate wire strands of the necklace. The brittleness of this alloy and the solid state transformation products indicate that the rods were formed by hotworking. The wires were probably formed by cutting from thin sheets of metal. Since this particular alloy can only be worked hot, a number of reheatings were necessary to form each rod: several to make the metal sheet and several more to allow removal of the strips. At the conclusion of the final shaping operation, each rod was quenched, probably in water, from a temperature in excess of 550°C.

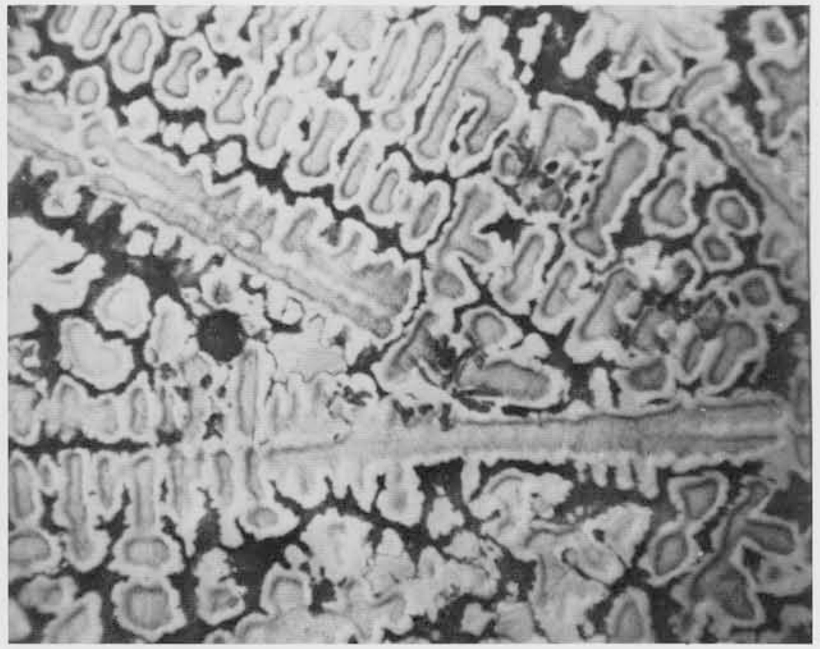
Since early Thai metalworkers were capable of producing a good bronze with about a 10% tin content, this high tin alloy must have been deliberate, perhaps because the lighter color imparted by 20% or more tin was desirable in an elaborate piece of jewelry. Usually this alloy develops a glossy black patina, but the excavators report that the necklace looked like tin when it was found, and the polished cross-section is lighter yellow than normal bronze. It is unlikely that a piece of jewelry would have been made for the dark patination, since patina is achieved with time and the pale color may represent an attempt to imitate silver.

Cyril Smith studied rings with a similar tin content from Pimai in northeastern Thailand, which date to the mid first millennium A.D. Although the rings were totally corroded, Smith saw the ghost structure of a similar martensitic transformation and commented that this alloy may have been more common than was suspected. The microstructure of the Ban Chiang necklace corresponds closely to that of the Pimai rings and a Korean bowl of the 12th-14th centuries A.D. studied by Voce. This high tin alloy was also used for Sassanian bowls and is best known in the West as cymbal metal. The Romans called it *speculum* metal and cast it into bells and mirrors. The Ban Chiang necklace is the earliest known Southeast Asian piece made of this alloy.

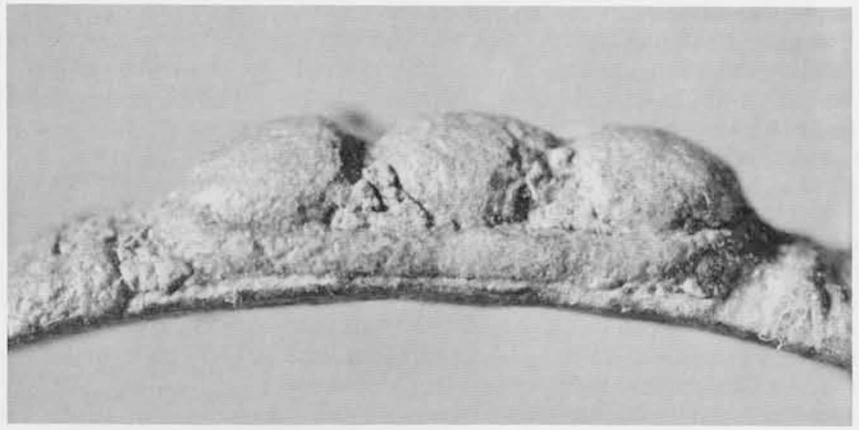
Two decorated bracelets from Non Nok Tha were examined to determine how the decoration was formed or applied. NP 1093 is a ring with small knobs set at regular intervals on one edge. NP 551 and its relatives from Burial 31, including the sample studied with decoration identical to that of 551, are D-shaped in section with four sets of decorations spaced evenly around the curved surface of the bracelet. Each decoration consists of six knobs, in two rows of three, with three parallel bands on each side of the knobs. Microscopic examination indicated that in each case the bracelet and decoration were cast as one piece, rather than the decoration being applied by welding or some other type of cementation, since dendrites were continuous from the decoration into the body of the bracelet. NP 551 shows indications of fast cooling. It is conceivable that bracelet 551 was cast by a type of lost wax process, a suggestion made because of the delicacy and regularity of the decoration. If the wax had been embedded in a thin clay rather than a stone mould, that would help explain the indications of fast cooling. After cooling, the knobbed areas on NP 551 may have been emphasized by incision. There is a thin groove at the junction of the knobbed area which is itself enclosed by a raised band that must have been part of the casting. The thin groove may have been made with a tracer since a mound of metal outlines the edges of the groove, indicating that no metal was removed. Although it is interesting to learn about the tool kit used by ancient craftsmen, the surface corrosion of the bracelet has obscured the details, so the use of a tracer cannot be proved.

1
Non Nok Tha NP 1093, bronze bracelet fragment, approximately 3.1 cm. long. Layer 17, 1300 B.C.

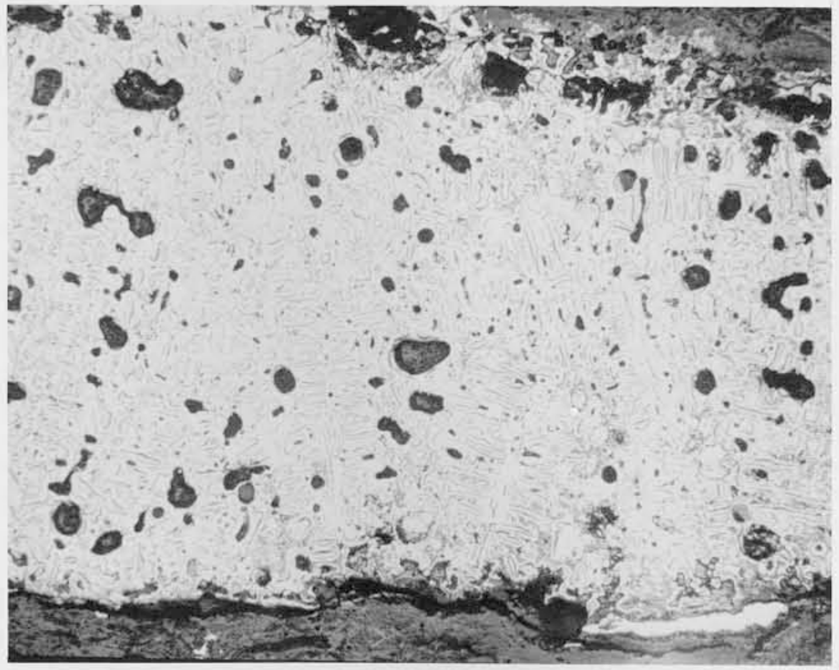
2
Non Nok Tha NP 551, bronze bracelet, approximate diameter 7.5 cm. Layer 17, 1000 B.C.

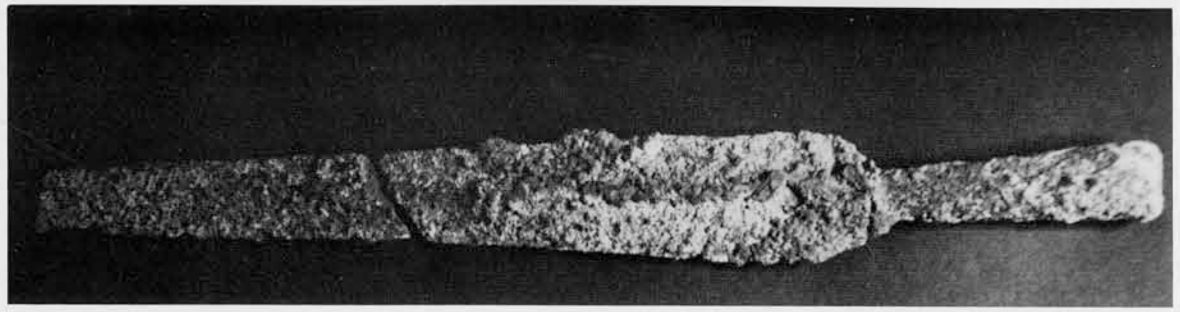


3
Non Nok Tha NP 551
Note the well developed dendrites which are continuous from the knobbed decoration into the body of the bracelet, indicating that decoration and bracelet ring were cast as a unit. X 200. Etched with ferric chloride.



4
Non Nok Tha NP 551, detail showing groove made by a tracer.





5, 6
Ban Chiang ES 1222, spearhead with iron blade and copper socket, 28.5 cm. long, Phase IV, 1600-1300 B.C. The optical micrograph shows a cast and unworked bronze structure. X 100. Etched with ammonium peroxide.

Although this discussion has concentrated on objects made of bronze and brass, iron objects were also found at Ban Chiang and will be included in complete analysis of the metal artifacts. One object with an iron component—a spearhead with bronze socket and iron blade dating to the period 1600-1300 B.C.—has been studied. The iron blade was made first and the bronze socket cast onto it. The socket was not worked after casting. The blade is totally corroded and is made of terrestrial iron, a fact confirmed by a scan with the electron beam probe. Only a minute amount of nickel was detected, proving that it is not made of meteoritic iron since a nickel content in excess of 4% usually indicates meteoritic iron. Corrosion of the blade is too advanced for any relic microstructures to be visible. There is very slight evidence of carburization which was impossible to photograph, so the blade should be regarded as a wrought iron which probably absorbed a small amount of carbon during forging. The presence of carbon in iron is most significant because it is carbon which transforms iron to steel.

The Ban Chiang spearhead is one of the earliest bimetallic objects found in East Asia and may be the earliest to contain wrought rather than meteoritic iron. Iron metallurgy on a large scale in China probably starts in the late Spring and Autumn period, perhaps around 600 B.C., but there were experiments with ferrous materials 400 to 600 years earlier. Since the accomplishments of ancient China are by no means fully known, the three bimetallic weapons discussed here may only hint at a wealth of unpublished and unexcavated material. Two ceremonial weapons with bronze handles, a broad axe (*ch'i*) and a dagger axe (*ko*), have blades of meteoritic iron. Although the provenance of these objects has been questioned, they are of well known types which can be dated to about 1000 B.C. A third bimetallic axe (*yueh*) came from Chinese excavations of a late Shang site at T'ai-hsi village in Hopei province. The iron blade of this axe contains 1.76% nickel, too little to be a certifiable meteoritic iron, although the excavator feels that the issue is not settled.

Both meteoritic and forged terrestrial iron were used in the eastern Mediterranean area and the Near East before ironworking technology became sufficiently advanced to render iron an acceptable medium for tools and weapons (1200-900 B.C.). The evidence presently available from East Asia suggests that a period of ceremonial and amuletic use of both meteoritic and terrestrial iron preceded the development of the Chinese ironworking technique *par excellence*—casting. The extremities of Asia may thus have become familiar with iron working in similar ways, with the experimental stage starting and ending later in China than in the eastern Mediterranean. The West developed techniques of turning iron into steel through the absorption of carbon and did not learn to cast iron, while China treated iron as it did bronze. Both areas continued to regard bronze as the superior medium for cast objects. Although only one Thai iron object has been examined, the appearance of the irons excavated at Ban Chiang and Non Nok Tha indicates that forging continued to be the major technique in Thai iron production. The history of iron working technology in Southeast Asia will be delineated through future research.

Some of the bronzes from Non Nok Tha and Ban Chiang show that the ancient Thai metal industry had achieved a considerable degree of sophistication before 3000 B.C., since by that date alloying, casting, coldworking and annealing were competently handled. The knowledge that a small amount of lead, less than 5% of the total weight of the material, would make the metal easier to cast by improving fluidity might also be attributed to the ancient smith. Since the information on early Thai metalworking has been developed from only two sites, further excavation elsewhere in Southeast Asia may show the beginnings of this industry and thus push back the date at which the possibilities of an important aspect of the natural environment were exploited. Metallurgy in Thailand was not static after the early development of the basic techniques of bronze working, since smiths continued to experiment and achieved results which had, at least, cosmetic significance. The Ban Chiang necklace reveals that an alloy which was difficult to work was used effectively in a complicated piece of jewelry for which a lighter color than normal bronze was desired. Early iron artifacts show interest in working with metals other than copper and its alloys.

Even a preliminary examination of a few of the more spectacular pieces in the larger corpus of ancient Thai metal objects reveals that metallurgical studies can make a significant contribution to the reconstruction of technology and society in early Southeast Asia. Future work on this material will help determine if all early Thai objects were equally well made or if differences in approach and technological achievements can be discerned. In addition, field research is now concentrating on locating mining and smelting sites and the number of excavations in the area grows annually. The role of metals and metalworkers in ancient Thai society will eventually be placed in local and global perspective, thus presenting archaeologists with the opportunity to understand better the processes of technological developments and invention.

Acknowledgments
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