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The Beginning of the Use of Metals and Alloys

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Edited by
Robert Maddin

size that this research is of particular significance in that, within a single geographical area at two distinct copper-producing locales, we have investigated all the major steps in the process of prehistoric copper production—a technological continuum spanning mining, ore dressing, smelting, and casting. Furthermore, such evidence should allow us to go beyond technological analysis to identifying activity areas and the patterns of their use.

Although it is still unclear, it is possible that the ore deposits at Phu Lon and Phu Ka were sources of native copper, the manipulation of which has yet to be recorded in Southeast Asia. Moreover, the substantial scale of copper production at sites documented by the Thailand Archaeometallurgy Project thus far suggests that production was occurring for a far wider universe than the immediate vicinity of the sites themselves. The Mekong and its tributaries and other important river systems within and around Thailand must have served as conduits along which people and most probably metals traveled.

As we await the completion of radiocarbon dating for this project, our initial impression is that, at least during the first millennium B.C. if not earlier, copper production was intense, continuing well into the period when iron was readily available, in the later centuries of the first millennium B.C. Evidence from both Phu Lon and the Khao Wong Prachan valley sites supports this contention. Analysis and interpretation of materials from these sites, currently underway, should provide significant insights into the processes by which early copper production evolved in Southeast Asia.

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15 Reflections on Early Metallurgy in Southeast Asia

Tamara Stech and Robert Maddin

We entered the controversial field of Southeast Asian metallurgy over ten years ago, when we became involved in the analysis of metals from the prehistoric village site of Ban Chiang in northeastern Thailand. Since the preliminary publication of this material (Stech-Wheeler and Maddin 1976), further metallographic studies have been performed[1] and a series of elemental analyses has been obtained by proton-induced X-ray emission (PIXE).[2] It therefore seems reasonable to go back to Ban Chiang at the outset and present the new information; then we examine it in broader context.

Ban Chiang

The Early Period

Of course, the basic problem in discussing Southeast Asian metallurgy is that of chronology [see, for example, Higham (1983, pp. 1–7)]. We are not independently qualified to pass judgment on the various chronologies proposed for Non Nok Tha, Ban Chiang, and Ban Na Di, but we do feel that White's basic outline for Ban Chiang is reasonable (White 1982, fig. 18 on p. 20). The fundamental question in this inquiry is when metal first occurred at Ban Chiang; White now believes that this happened c. 1700 B.C. Therefore the early period in terms of metal usage is placed conservatively at c. 1700–1000 B.C.

At this point in the study of the Ban Chiang artifacts it is not possible to determine the total quantity of metal that can be assigned to each period. Artifacts range in size from droplets to axes, according to White, so a simple count would not adequately reflect the nature of production or usage.

At present, metallographic studies of six Early Period artifacts have been completed and elemental analysis has been performed on five of these. The three bracelets were left in the as-cast condition, which means they were not worked (figures 15.1 and 15.2), and tin is present in all of them in amounts ranging from 5.5% to 12.4% (see table 15.1). It should be noted that all are internally corroded, and therefore the levels of tin now detectable may not reflect the original composition. The high tin readings could result from an enhancement of the tin value by the corrosion process or from an aspect of the PIXE instrumentation or both. An adze, left in the as-cast condition (BC 694/1203; figure 15.3) is also so corroded that the presence of 18.4% Sn is questionable; indeed the microstructure is metallurgically incompatible with that amount of tin; that is, other metallurgical phases should be visible in the microstructure.[3] An adze with this amount of tin would not be functional in any operation involving impact because it would be highly brittle. The same comment concerning the metallurgical microstructure would also apply to an unidentified fragment (BC 679/1071). Spearhead BCES 762/2834, originally touted by us as

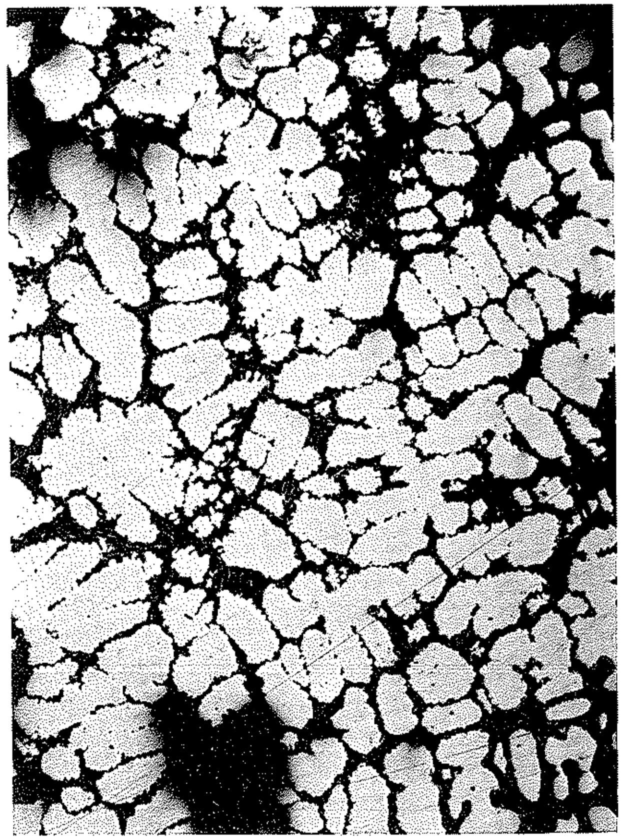

Figure 15.1 Bracelet BC 693/1203 shows a well-defined cast structure and a large grain size. × 100.

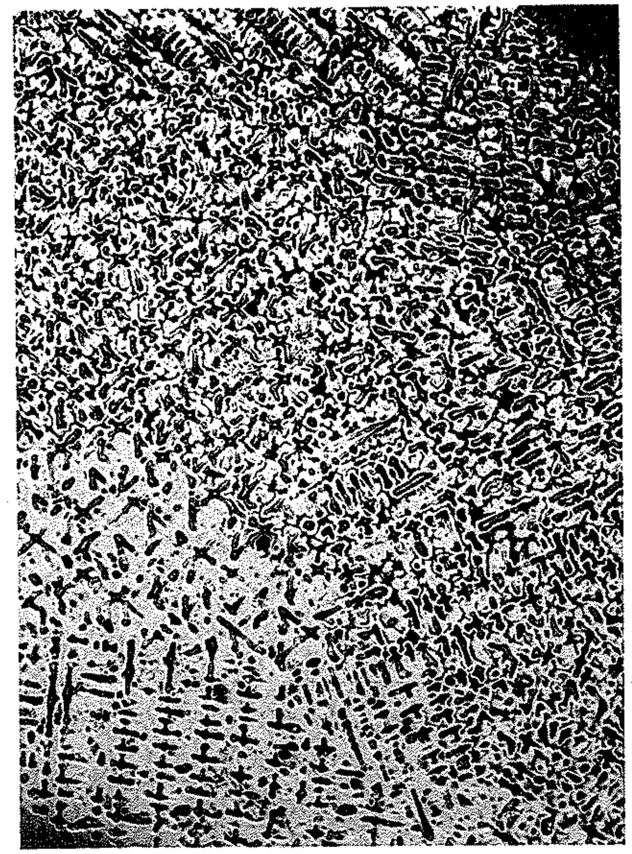

Figure 15.2 Bracelet BC 722 shows a dendritic pattern characteristic of a cast structure. × 100.

Table 15.1 Elemental analysis (PIXE)[a]

Sample	Cu	Sn	As	Ni	Pb	Fe	Ag	S	Si	Sb
Early Period										
BC 693/1203	86.7	12.4	0.095	<0.011	0.107	0.049	0.052	0.019	0.01	0.032
BCES 596/1984	89.6	9.5	0.114	0.029	0.044	0.017	0.117	0.19	0.12	0.055
BC 694/1203	80.4	18.6	0.094	<0.011	0.122	0.03	0.145	0.066	0.066	0.047
BC 679/1071	79.7	18.4	0.093	<0.011	0.121	0.08	0.047	0.101	0.066	0.047
BCES 762/2834										
Socket	90.0	9.17	0.101	<0.012	0.084	0.153	0.029	0.039	0.02	0.026
Blade	91.7	7.73	0.105	<0.012	0.081	0.111	0.018	0.048	0.016	0.035
Middle Period										
BCES 490/1286	92.9	6.2	0.057	<0.01	0.079	0.016	0.027	0.40	0.133	0.023
BCES 491/1286	86.0	13.3	0.163	<0.01	0.026	0.019	0.011	0.375	0.126	0.018
BCES 591/1981	84.4	12.1	0.135	<0.01	1.46	<0.018	0.149	0.267	0.096	0.397
BCES 395A/1115	90.1	5.5	0.119	<0.012	4.03	0.041	0.051	<0.006	0.016	0.054
BCES 616/2097	75.3	14.1	0.04	<0.009	9.93	0.055	0.052	<0.013	0.072	0.011
BCES 617/2097	84.5	13.9	0.141	<0.01	0.054	0.031	0.017	0.296	0.101	0.045
BCES 609/2069	69.6	16.1	0.071	0.011	13.0	0.069	0.05	<0.02	0.149	0.064
BC 708/1594	93.6	5.6	0.92	<0.011	0.036	0.282	0.035	0.36	0.098	0.086
BC 2188/530	88.3	10.0	0.313	<0.01	0.336	0.282	0.035	0.36	0.098	0.086
BCES 480/1367	85.2	10.6	0.056	0.016	1.27	<0.02	0.045	0.227	0.06	0.04
Late Period										
BC 2160/276	68.8	12.3	5.63	0.029	12.5	0.032	0.23	<0.007	0.031	0.297
BC 604/492	61.2	18.8	0.376	0.017	18.3	0.02	0.289	0.018	0.234	0.118
BCES 288	89.4	6.8	0.274	0.019	3.11	0.034	0.104	<0.007	0.019	0.169
BC 2156/322	77.2	10.1	0.125	<0.010	12.0	0.042	0.09	<0.011	0.036	0.086
BC 2161/781	74.0	24.8	0.205	<0.008	0.04	0.06	0.151	0.025	0.257	0.152
	80.7	17.9	0.154	<0.009	0.032	0.03	0.119	0.235	0.088	0.098

a. All values given as percentages.

Figure 15.3 Adze BC 694/1203 is heavily corroded and shows a cast structure. × 100.

"the earliest piece excavated at Ban Chiang dated to 3600 B.C." (Stech-Wheeler and Maddin 1976, p. 41), was cast as a unit (figure 15.4 bottom and figure 15.5 right), presumably in a bivalve mold, worked, and annealed. The micrographs show that the recrystallization of the grains strained by cold-working was not complete. The spearhead has 9.17% tin, according to the PIXE analysis. In 1976 we reported that this spearhead contained 1.3% tin but noted that the real value could be as much as three times that number because the method of detection (optical emission spectroscopy) was only semiquantitative with respect to tin. In addition, the caveats applied to the PIXE analysis should be noted—possible enhancement of the tin value by corrosion or an aspect of the PIXE instrumentation or both. The fact remains that, because of the extent of the internal corrosion, we will never obtain elemental analyses that show the original composition.

What does this limited sample tell us about the metals used in the Early Period at Ban Chiang? First, that casting was competently handled, alloying of copper with tin was known, and working and annealing were practiced. These basic techniques of copper working seem to have appeared full blown at Ban Chiang.

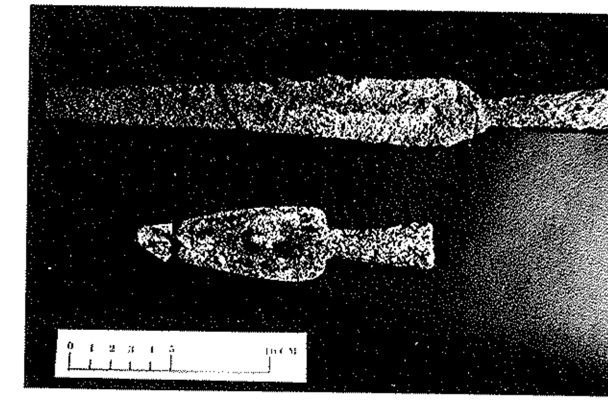

Figure 15.4 Spearhead BCES 762/2834 (bottom).

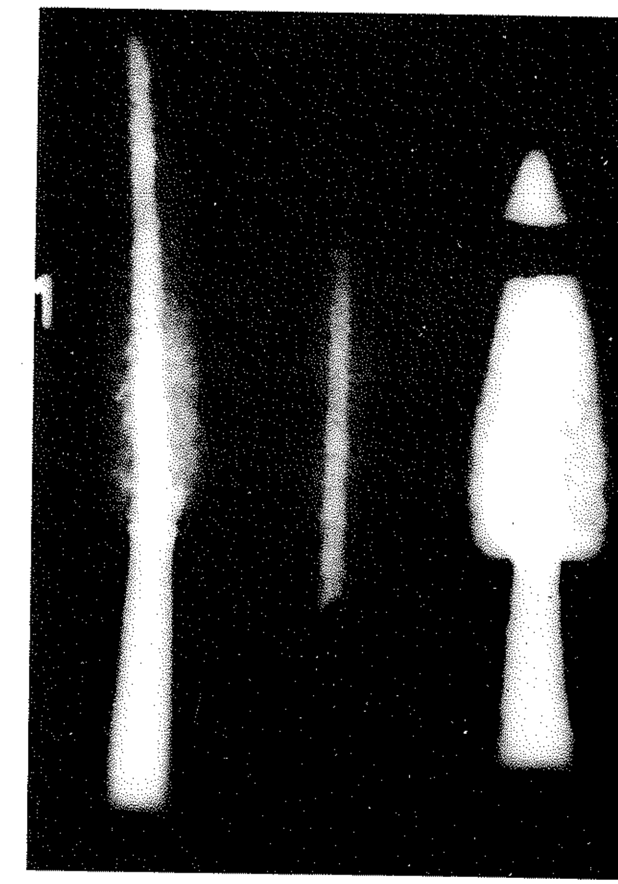

Figure 15.5 Radiograph of spearhead BCES 762/2834 (right).

The Middle Period

Bronze ornaments, primarily bracelets and anklets, were frequent in Middle Period graves, with crucibles appearing early in the period. This span is dated c. 1000–300 B.C. and is the time when iron enters the record at Ban Chiang, at least by the middle of the period, although a few small fragments are present in the earlier portions of the Middle Period, according to White (personal communication).

Eight bracelets and anklets (BCES 490/1286, BCES 491/1286, BCES 591/1981, BCES 395/1115, BCES 616/2097, BCES 617/2097, BCES 609/2069, BC 708/1594; figures 15.6–15.10) and two other artifacts of bronze (BC 2188/530, BCES 480/1367) have been studied metallographically. All were left in what is defined metallurgically as the as-cast condition, a technological indication that is probably prejudiced by the preponderance of bracelets in the sample but one that demonstrates the skills of early Thai metalworkers in achieving the desired product. Tin contents range from 5.5% to 16.1%, but again all the samples are corroded so these values may not reflect the original compositions. In contrast to the bronzes of the Early Period, however, are the levels of lead—five of ten artifacts analyzed contain more than 1% (1.27%, 1.46%, 4.03%, 9.93%, 13.0%). As we discuss later, the addition of lead seems to be deliberate.

Although the bronze industry is stable and accomplished, innovation occurs in the making of bimetallic—bronze and iron—and solely iron artifacts. The collection consists of iron bangles and two bimetallic spear points. One of the spear points (BCES 548/1582) has been studied. Its iron blade is extensively corroded, so it has yielded little information, but it appears to have been made from terrestrial iron because it contains only a minute amount of nickel. Nickel in excess of 4% and a metallographic structure characteristic of meteoritic iron are needed to prove a nonterrestrial origin. The blade must have been forged into shape and the bronze socket cast into it. The socket is bronze (determined qualitatively) with large discrete globules of lead distributed throughout at least the area of the sample.

The Late Period (c. 300 B.C.–A.D. 200)

White notes that, although no iron ornaments occurred in the excavated burials dating to the Late Period, iron was used for tools and weapons (White 1982, p. 45). Bronze bangles continue and bells appear, but the major innovation was a variant of bronze technology—a high-tin alloy with unusual manufacturing requirements.

Six artifacts of normal bronze were studied—four bracelets or bangles (BC 2160/276, BC 604/492, BCES 288, BC 2156/322; figure 15.11) and two fragments, only one of which (BC 2161/781) was analyzed. Five were left in the as-cast condition, as proved by their

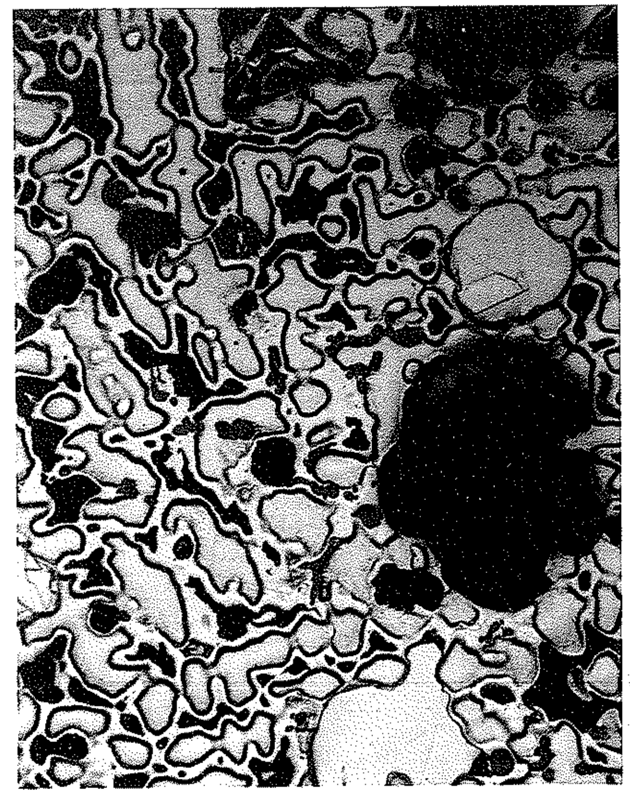

Figure 15.6 Bracelet BCES 490/1286 left in the as-cast condition. × 200.

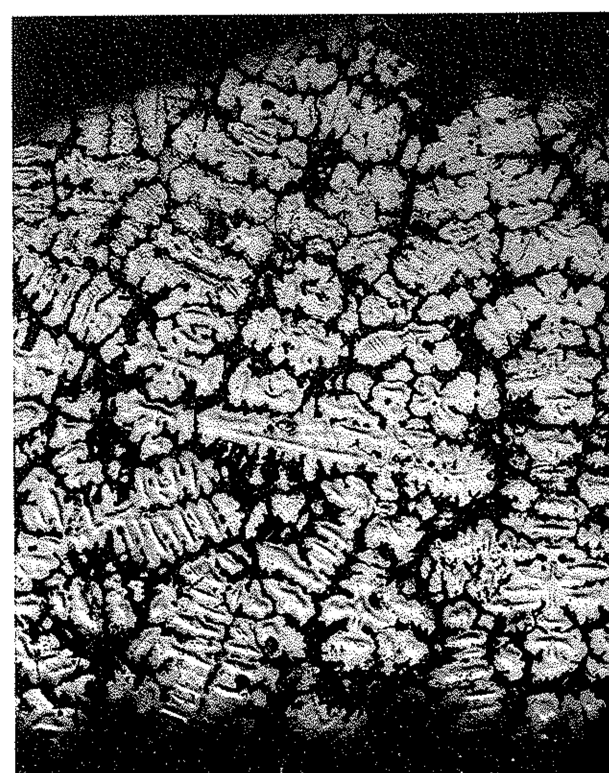

Figure 15.7 Bracelet BCES 591/1981, with 12.1% Sn, is not as heavily corroded as BCES 491/1286, and it shows a well-defined dendritic pattern. × 100.

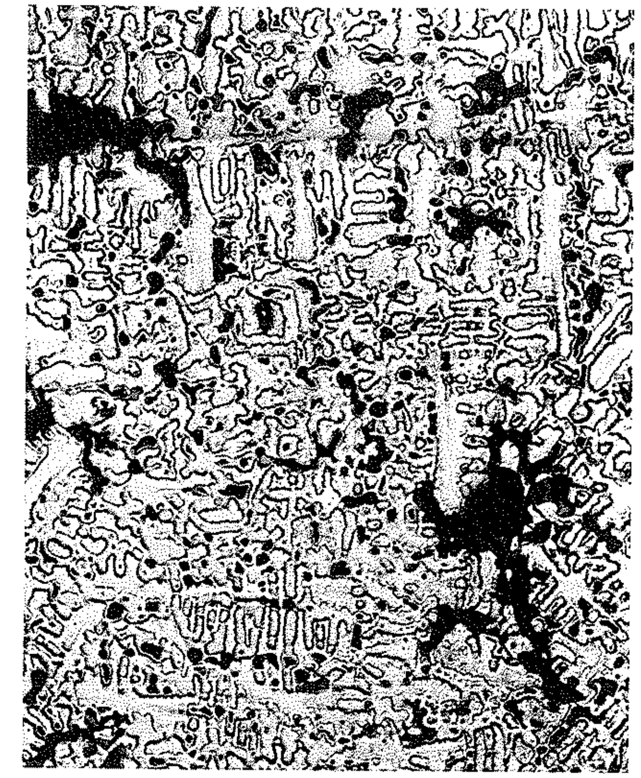

Figure 15.8 Bracelet/anklet BCES 395/1115, with 5.5% Sn and 4.03% Pb, shows a two-phase structure and an as-cast structure. The black areas are due to corrosion. × 100.

Figure 15.10 Bracelet/anklet BCES 708/1594, a low-tin bronze (5.6%), was left in the as-cast condition. × 100.

Figure 15.9 Bracelet/anklet BCES 617/2097, with a chemical content similar to BCES 395/2097 but with little Pb (0.054%), shows a sharp dendritic pattern. The black areas are the interdendritic sections that have corroded. × 200.

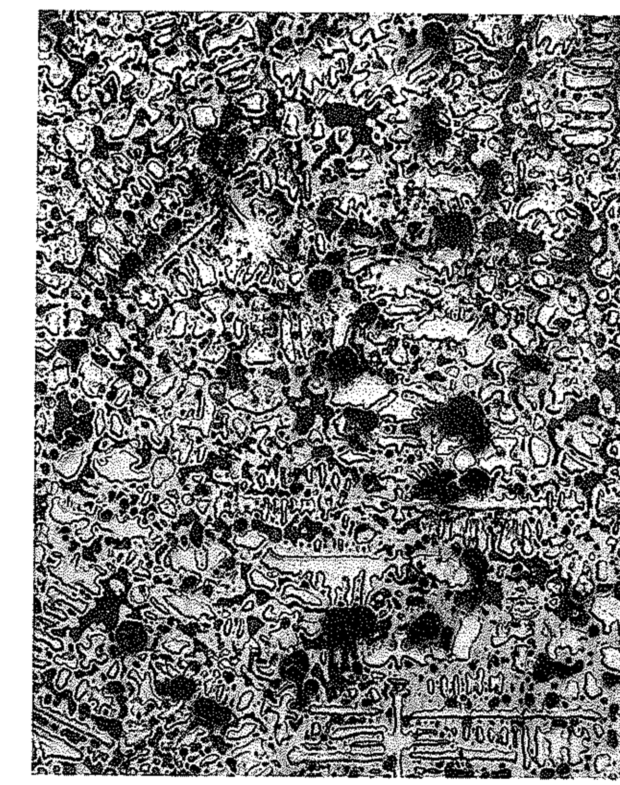

Figure 15.11 Artifact, not analyzed, shows a two-phase structure with a dendritic pattern characteristic of the as-cast condition. × 100.

dendritic structures. The sixth is extremely corroded, so it is difficult to determine the original structure; it might have been worked. Of the four for which we have elemental analyses, the tin contents range from 6.8% to 24.8%. Those quantities of tin above 11% seem suspicious, however, because the microstructures are not compatible with the amounts. The analyses must be exaggerated, for the reasons given before.

The high-tin bronze from Ban Chiang from the grave of a five-year-old child (BC 918/10; figures 15.12 and 15.13) that we have examined is a necklace made up of hundreds of thin rods, some straight and some helical. We discussed the metallurgy of this necklace extensively in 1976 (see figure 15.13). Since then we have obtained an elemental analysis of one section that is undoubtedly too high at 68.7% tin. Subsequent studies have shown that alloy to be represented at Don Klang, near Non Nok Tha, in levels dating to the first century A.D.

An oddity is a brass ring, which may be the accidental result of smelting ore with zinc minerals included perhaps in the attempt to add lead.

Two iron tools and an unidentified iron piece were also analyzed. One tool (749/2669) shows a significant carbon content along the edge (figure 15.14), which *may* suggest an attempt at case carburization—allowing the finished artifact to remain in the forge long enough to render the edges steel and hence making those edges much stronger. There is no further evidence of manipulation of "steel" in terms of quenching and tempering. The other two artifacts have essentially ferritic structures with no evidence for extensive contact with carbon (see figure 15.15). One artifact (1205/580) contains slag stringers, which demonstrate the direction of forging.

Thus, to summarize our scientific evidence on Ban Chiang, bronze working started in the first half of the second millennium B.C., with some slight evidence for a stage of experimentation immediately preceding the first accomplished attempts at production. This competent bronze industry, characterized by considerable skill in casting intricate shapes, persisted into the first centuries A.D. About a thousand years after the first bronze appears in the burial sequence at Ban Chiang, iron was introduced. This iron seems to have been forged from the products of smelted ores. There is at present little evidence that intentional steel was made at any time during the ancient occupation of Ban Chiang, but the sample studied is small. In addition, there is no way of determining metallurgically whether the "ferritic" iron examined was not obtained by the decarburization of a high-carbon iron, that is, cast iron. A further testament to the skills of the bronze workers is the use after 300 B.C. of a high-tin alloy, which is at best difficult to work, for ornamental purposes.

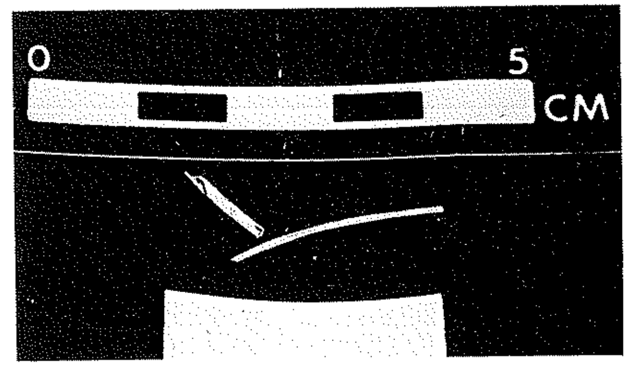

Figure 15.12 Pieces of high-tin bronze that made up "Bianca's" necklace.

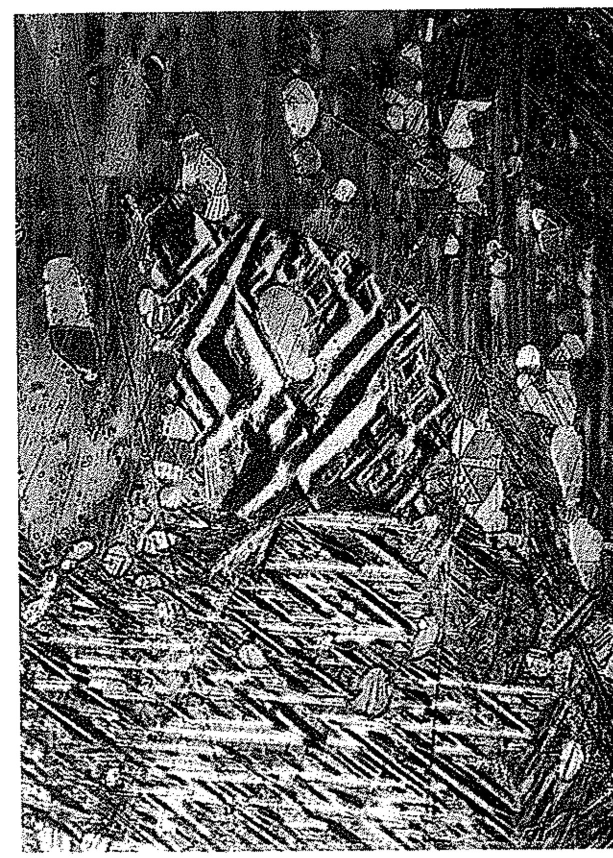

Figure 15.13 High-tin bronze (BC 918/10 with as much as 24% Sn) shows the beta-Sn martensite structure resulting from quenching the bronze from above 520°C. × 100.

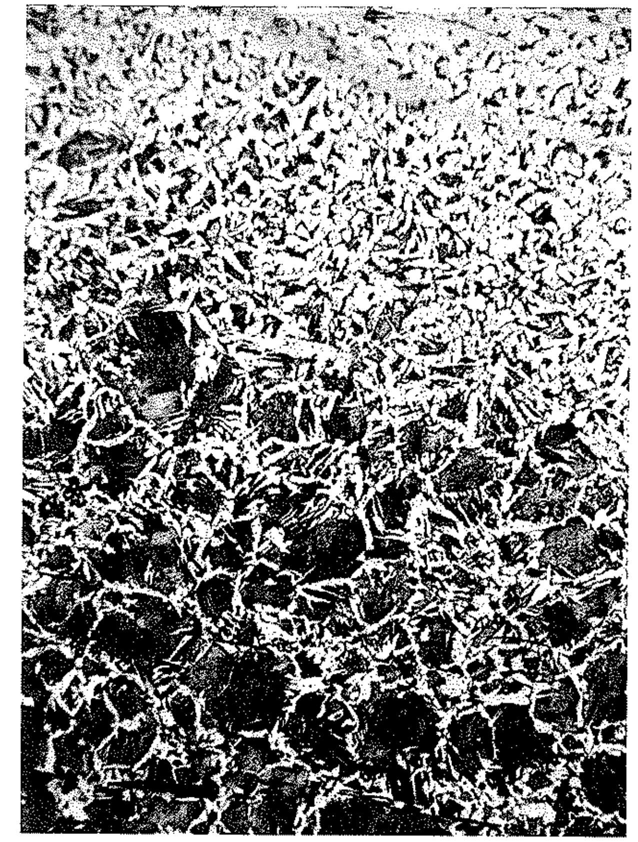

Figure 15.14 Iron tool BCES 749/2669 shows a significant amount of carburization along its edge. × 100.

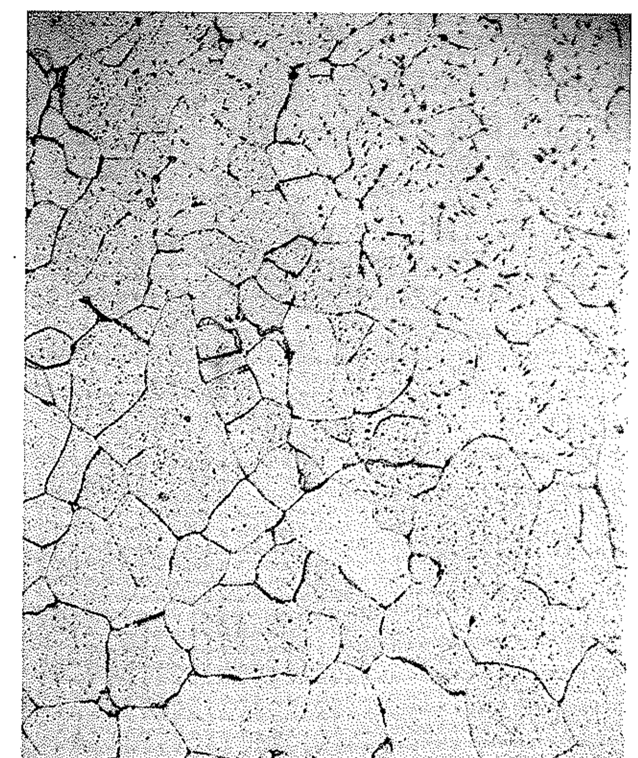

Figure 15.15 Ferritic structure showing no evidence for any carburization. × 500.

The Origins of Bronze Making in Thailand

It is clear that at this time we cannot say if the Thai bronze industry was independently invented or derivative. On the basis of the published evidence, the earliest bronze is claimed for Non Nok Tha, at some time during the third millennium B.C. (calibrated dates) (Bayard 1984, p. 165). This evidence would then predate that at Ban Chiang, a site that was also inhabited since the fourth millennium B.C. In the absence of the final report on Non Nok Tha, we cannot assess at the evidence in relation to other excavated sites. It is certainly not impossible that different sites started using bronze at different times, but the sample is so variable that we cannot tell. In the broader context of Southeast Asian bronze production, it is important to note that bronze metallurgy can be documented in Vietnam in the second millennium B.C. (Diep 1978; Higham 1983, p. 6), a date more consistent with that proposed for Ban Chiang than for Non Nok Tha. Higham (1983, note 4) questions that Non Nok Tha was inhabited before the second millennium B.C., so perhaps we can generally place the earliest bronze usage in the early second millennium B.C. The firm point is that present evidence shows that bronze did appear full blown, with little or no evidence for a period of experimentation.

Given, however, the geological situation—deposits of copper in northeastern Thailand and of tin not too distant in Cambodia and Laos—it might be reasonable to assume that experimentation took place in the source areas and that the abundance of the resources made only a (relatively) short period of experimentation necessary. Our view of Southeast Asian metallurgy has been strongly affected by the roughly evolutionary sequence of metallurgical development in Southwest Asia—native copper usage[4] preceding copper smelting, arsenical alloys of copper followed by those with tin. The area of Southwest Asia in which, so far as we now know, copper metallurgy advanced most rapidly is the resource-poor Mesopotamia. The introduction of tin as an alloying element may relate more to its extreme rarity in Southwest Asia rather than to the inexorable march of technological progress [see most recently, Stech and Pigott (1986)]. We simply do not have a model to deal with the development of bronze alloying in an area rich in the necessary resources. Given the availability of the appropriate resources, there is no reason why early Thai metalworkers could not have worked out the technology in their own milieu, although the low-fired pottery does not suggest great pyrotechnological skill.

Although Southeast Asia is well known as the site of the world's richest tin deposits, little geological research has been done from the point of view of prehistoric metalworkers. Modern economic viability of ore deposits is not the same as ancient viability, so reconstruction of the locations of deposits potentially useful to ancient miners is at present difficult.

Bronson (1985b) has compiled evidence for copper and tin deposits. Copper deposits cluster in three subregions: the northern and central Philippines, the northern mainland, and Sumatra and Java. Only the Philippines and the northern mainland can be described as moderately copper rich. The rest of Southeast Asia is more or less deficient in copper deposits, including the Mekong delta and Cambodia and a broad belt that extends from the Malay Peninsula eastward to the Maluccas. Even if we had no historical information on the subject, we could be justified in concluding that much of the region has always been short of smelted copper (Bronson 1985). Although, as elsewhere, there must be small deposits that are not economically viable and therefore not the subject of modern geological research, the implication is that the northern mainland—Burma, Thailand, and a few parts of Laos and Cambodia [the last deduced from Bronson (1985b, fig. 2), although this is in conflict with his text]—would have been the most likely areas in which the alloying of tin and copper could have first taken place. The Philippines only began to make metal in the closing centuries of the first millennium B.C., and the metal of choice was iron, a development that came about because of Chinese influence.

On tin, Bronson says:

Estimates of reserves are traditionally unreliable in the tin industry, but all authorities agree that Southeast Asia with Yunnan contains more than half of the world's tin. . . . The northern mainland and southern China contain a fairly large number of scattered deposits. All the rest of the tin is concentrated into a single belt that runs from the eastern side of central Burma down through the Kra isthmus and the Malay Peninsula to the islands of Singkep, Bangka and Belitung. Adjacent parts of Sumatra have a few small deposits and the whole of the Philippines have none at all. (Bronson 1985b, p. 30)

Thus southern Burma, northern Thailand, and northern Thailand, and northern Cambodia contain both elements necessary to make bronze. The archaeological evidence for northeastern Thai bronze production, although it could be skewed by chance, may be better than it appears, because the broad general concurrence of archaeology and geology is striking. Because Vietnam is not one of the geologically favored areas, the presence of bronze there in second millennium B.C. contexts may indicate that exchange of the raw materials and communication of technological knowledge took place rapidly.

The broad general resolution of the chronological issue, Bayard and Solheim's preliminary statements notwithstanding, leads to the striking realization that a technological continuum seems to have existed across Southeast Asia, starting in the case of metals with bronze working in the second millennium B.C. and continuing into the first millennium B.C. with leaded bronzes, iron, and high-tin alloys of copper. In a forthcoming article on metal articles from Samrong Sen, Cambodia, now in the Peabody Museum, Harvard University, Robert Murowchick cites the similarity of techniques, crucibles, and bivalve molds and adduces that "this close correlation between the Samrong Sen material and that from Ban Chiang, Non Nok Tha, Mlu Prei and other sites suggests that the metallurgical know-how was disseminated along the various trade routes joining Thailand, Cambodia and Vietnam." The area in which the expertise was developed cannot be located precisely, if there was indeed a single location, but odds are that it was one with both copper and tin deposits.

Leaded Bronzes

As Murowchick points out, leaded bronzes are a phenomenon of the first millennium B.C. Seeley and Rajpitak (1984, pp. 106–107) detected lead in Ban Na Di bronzes in 32% of the artifacts. Again, the earliest occurrence of leaded bronze on a regular basis would seem to be at Non Nok Tha, where it was made by Middle Period 3, some time in the third millennium. The large number of bronze nodules, which Bayard identifies as casting spillage, are, however, virtually free from lead, indicating that the lead was added after the initial melting of the bronze (Bayard 1981, pp. 697–698). Following the common wisdom, Seeley and Rajpitak and Bayard attribute the presence of lead to the improved fluidity it imparts to the casting of the alloy, thus enhancing the smith's ability to make complicated decorative items. White has noted that the shapes of bracelets in the Middle Period at Ban Chiang are, in fact, considerably more elaborate than those of the Early Period. The Ban Na Di sample consists largely of bracelets and rings, as does that from Ban Chiang. Seeley and Rajpitak wonder whether the presence of lead has chronological implications (1984, p. 107), which might be indicated by the sequence at Ban Chiang, where leaded bronzes occur first in the Middle Period and never in the Early Period sample. The evidence from Non Nok Tha, if the dating is anywhere near correct, would, however, vitiate this tentative conclusion.

Four of the five artifacts from Samrong Sen analyzed by Murowchick contain lead (6.82–26.47%) but, because of their uncertain dating, they merely confirm the general trend rather than contribute to the debate. It is again clear that we cannot even begin to resolve such questions until the final reports on Ban Chiang and Non Nok Tha are available.

For information on sources of lead, we turn again to Bronson:

Lead and zinc, which tend to occur together in the same deposits, are distributed rather differently from copper. . . . The northern Mainland is abundantly furnished with lead-zinc ores, and part of that subregion—Burma—is exceptionally rich. The two metals are also much more likely than is copper to be present in other parts of Southeast Asia. . . . Only Cambodia and the Mekong Delta are actually lead and zinc deficient. The rest of the region has at least moderate quantities of the relevant ores. (Bronson 1985b, p. 25)

Because zinc volatilizes or passes off as a gas (ZnO) at temperatures where the lead is still liquid, most of it would have disappeared during smelting, resulting in a fairly pure lead as the end product. The analyses from Ban Chiang (table 15.1), Ban Na Di (Seeley and Rajpitak 1984, p. 108 and table 3-21), and Samrong Sen (Murowchick, forthcoming) show that the leaded bronzes contain low levels of zinc. Lead-zinc, copper, and tin deposits occur in relative proximity in central Burma, northern Thailand, and northern Cambodia. The intimacy of association of the three mineral types in most places is not known; that is, it is not known if in other places in the region the lead-zinc ores actually co-occur with those of lead and/or tin.

High-Tin Bronzes

The few high-tin bronzes known from Late Period Ban Chiang and the nearby site of Don Klang are paralleled at Ban Na Di in three certain and two probable specimens. Most of the known artifacts made of alloys of this type are ornaments; the bowls of Ban Don Ta Phet (Rajpitak and Seeley 1979) are an interesting exception, probably made for a special decorative purpose. The consensus is that high-tin bronze was made because it was lighter in color and could be rendered shinier than normal bronze (Seeley and Rajpitak 1984, p. 107; Stech-Wheeler and Maddin 1976, p. 43). The difficulty of fashioning must have contributed to the apparent infrequency of use and therefore the value.

Containing about 24% tin, high-tin bronze presents a striking phenomenon in a region where silver and gold are rare to nonexistent in the archaeological record. Its occurrence may reflect the desire to convey status through adornment, with the time and care needed to produce ornaments factors determining value, perhaps almost as much as the appearance. Thus the frequency of tin in Southeast Asia may be the technological factor that enabled the cultural need for display to be fulfilled.

Iron

Iron appears at Ban Chiang in the middle of the Middle Period, by 500 B.C. or earlier in the first millennium. The conclusion reached on the basis of studying a few artifacts, as described earlier, was that they are made of forged bloomery iron, not meteoritic and probably not decarburized cast iron, and that no deliberate attempt was made to convert them into steel.[5]

In assessing how iron use at Ban Chiang fits into the general scheme for Thailand and the rest of mainland Southeast Asia, we are once again indebted to Bronson. His review of the available radiocarbon dates for early iron in Thailand leads him to conclude that this phenomenon can be dated to the first half of the first millennium B.C., which is well before any intensive contacts with India and China (Bronson 1985a, pp. 205–208; Pigott and Marder 1984).[6] This date is roughly in line with that of the flourishing ironworking technologies in many other parts of the world, including southwest Asia, the eastern Mediterranean, and Europe.

The technological arguments adduced by Pigott and Marder (1984, pp. 278–281) support the contention that Thai ironworking could have developed out of the millennium-old bronze working tradition. In their tentative reconstruction iron could have been encountered first under certain conditions in the copper smelting furnace, if iron oxide contained in copper ore (for example, chalcopyrite) or a hematite flux was used in smelting the siliceous ore. Although detailed evidence on the mineral form in which all Southeast Asian copper minerals occur is difficult to assemble, Murowchick does note the presence of chalcopyrite in both Thailand and Cambodia. There is at present no reason to suppose that iron smelting was not an indigenous Southeast Asian development.

Ban Don Ta Phet dates to the last centuries of the first millennium B.C. but before the strong Indian and Chinese influences on Southeast Asia. Most of the thirteen artifacts analyzed by Bennett were made of low-carbon steel and were air cooled and sometimes edge-hardened by hammering. Bennett concludes:

The smelting of small sized limonite pellets found in the area would have produced the fairly homogeneous low carbon steel. That this had been extensively forged was shown by the small number of slag inclusions remaining. . . . The tools, and the rest of the weapons, were made by simple techniques and no attention seemed to have been paid to the degree of decarburization during forging. There was no evidence of the use of sophisticated quenching and tempering treatments. However, the implements appeared to be well adapted to their function. They were of a hardness which would have prevented them from becoming blunt too quickly and would have enabled them to be easily sharpened. The working edges of some tools appeared to have been hardened during use. (Bennett 1982, secs. 9.2 and 9.3)

The second major metallurgical study analyzed among others four artifacts excavated at Don Klang (Pigott and Marder 1984, pp. 283–289). Two of these are made of low-carbon, possibly air-cooled steel, and a third artifact has a higher carbon content but shows no evidence of having been quenched; these three date between 300 B.C. and A.D. 210 (calibrated carbon 14 dates). The fourth artifact dates earlier, c. 390–395 B.C. (calibrated carbon 14 date); it is so completely carburized that Pigott and Marder believe it to have been intentionally steeled and cooled in an accelerated fashion, perhaps by quenching. Of the four additional artifacts reported, one appears to have been deliberately carburized, whereas the others are low-carbon steels that probably became steeled in the forge. All were apparently cooled in an accelerated fashion.

The evidence, then, is somewhat variable in details, that is, as to whether good steels could be made, but it is clear that low-carbon steel could be produced fairly regularly and that it would have probably been adequate for most of the requirements of agrarian people in the environment of Southeast Asia—digging, harvesting, and processing of roots, grains, and fibers and of animal products such as skins.

Final Remarks

It is most productive, particularly given the incomplete state of our knowledge, to try to understand Southeast Asian metallurgy in its own context rather than to compare it to technologies half a world away. For example, apparently lacking in Southeast Asia are the steps that led to the bronze industry in southwest Asia; but the raw materials are not lacking, which is interesting in relation to several arsenical copper artifacts from Ban Na Di (Seeley and Rajpitak 1984, p. 107), one containing 3.56% arsenic and 4.85% tin, and from Ban Chiang (no. 2160/276; see table 15.1). Although they fall late in the first millennium B.C. at both sites and thus cannot occupy a place in any evolutionary sequence, they do indicate that arsenic minerals were available, but they seem to have been ignored or not recognized. From his review of the literature, Bronson concluded that arsenic must have been present in the copper deposits of Southeast Asia, although only nineteenth-century smelting of copper-arsenic ores in northern Luzon can be cited in support (Bronson 1985b, p. 33). The rare presence of arsenic in late bronze artifacts in Thailand was probably not perceptible to the metalworker because the amounts are too low to have had much effect on the physical appearance or obvious properties.

In ironworking also the industry appears to remain largely stable so far as it has been traced, perhaps because the product responded sufficiently to the relatively constant needs of its users. Lack of change in some part of the cultural and ecological system that would have occasioned changes in the products needed to sustain the system meant that ferrous technology and its tools were and remained adequate.

In this context we should cite the fact that early iron in southwest Asia was by no means always fully manipulated, that is, carburized, quenched, and tempered. By comparison, current evidence indicates that the eastern Mediterranean littoral was the site of such developments [see, for example, Stech-Wheeler et al. (1981), Davis et al. (1985), and Maddin (1982)], whereas the Assyrians of inland southwest Asia, who are the documented consumers of tons of iron, were using virtually pure iron (Curtis et al. 1979) as were their neighbors in northwestern Iran (Pigott 1981). The reasons for the differences in approaches to ironworking techniques must lie to a certain extent in the nature of raw materials available, to environmental conditions prevailing in each area, and to the individual cultural requirements of each iron-using group.

In this vein one might speculate along the lines of the "peaceful Bronze Age" of Thailand (White 1982), which would have given way to a "peaceful Iron Age" until perhaps Chinese and Indian influences exerted different pressures on local development. To harvest rice, dig roots, and chop bamboo, low-carbon steels would have been adequate. In Southeast Asia the indications of differentiated social structure are not as sharp as they are in southwest Asia and the eastern Mediterranean in the early part of the first millennium B.C. In Thailand Higham sees a "major discontinuity" between 400 and 200 B.C. (Higham 1983, p. 16), perhaps occasioned by an externally generated disruption of the "peaceful" cultural continuum. In the eastern Mediterranean a "major discontinuity" occurred c. 1200 B.C., one that seems to have involved considerable hostilities and movements of peoples, with much of the activity centering around areas that are certainly not as agriculturally sympathetic as Thailand. A concomitant catalyst for relocation in marginal or undeveloped agricultural zones might have been the development of what we would characterize as a more sophisticated ferrous technology (that is, one producing carburized, quenched, and tempered steel) that responded to changes and uncertainties in all aspects of life, including the major one of producing food.

The explanation of why Neo-Assyrians and their Iranian neighbors did not participate in or share the developments of the Mediterranean littoral is even more complicated. One possibility is that the technology did not come about because the adversity of various aspects of life did not exist. Neo-Assyrians used bronze regularly; the mention of great quantities of iron in their texts may reflect stockpiling of a material that was culturally valuable in that it conferred status on the new empire. Pigott (1981) has suggested that Iranian iron usage was in emulation of Assyrian usage. We might extend that hypothesis to say that Neo-Assyrians used iron in imitation of their neighbors

to the west, without the specific knowledge of what made iron essential to the peoples of the Mediterranean littoral.

Therefore the skills of the Thai ironworkers are not to be denigrated but rather praised for the successful development early in its history of an iron that filled their needs. We know too little about the sequel to the "major discontinuity" in Thailand to comment on the response of technological systems to changed circumstances, but we can speculate that the ironworking skills demonstrated by the existing metallographic studies were appropriate in their context.

Rather than look for evolutionary patterns and inventors, we might disagree with Higham and Kijngam's statement (1984, p. 1) that "the indigenous development of bronze and ironworking in inland Southeast Asia in a context of unchanging, stable, small-scale communities" is an interpretation that "if validated, would run counter to any notion of even the most general regularities of culture process." Technological systems, such as metallurgy, should be interpreted as integral parts of the cultural context in which they occur rather than as entities possessing their own dynamic, independent of context, which is uniform through time and space. Bronze metallurgy in southwest Asia flourished at a time of urban nucleation when some elements of the population had a strong cultural need to demonstrate status. Metals, as imported materials often brought from considerable distances, partially fulfilled that need in their role as exotic commodities. In Southeast Asia metallurgy developed in the context of an agrarian society that did not, before perhaps the last centuries B.C., experience discontinuities on a scale with those occurring in southwest Asia with some relative frequency starting by at least the late fourth millennium B.C. Southeast Asians also had much easier access to all metals than did their counterparts in the southwest. Metallurgy did not change the cultural dynamics in either end of Asia but was a dependent subsystem in both areas, as it was elsewhere. Southeast Asian metallurgy can be understood only when it is viewed as an industry that developed in a fairly uniform and peculiarly regional manner, based on an abundance of local natural resources. This feature makes Southeast Asia distinct from Old World culture areas on which our current models of metallurgical development are posited and requires that we make new models appropriate to a different environmental and cultural setting.

Notes

An earlier version of this chapter appeared in the *Bulletin of the Metals Museum* (1986), 11:43–56.

1. This chapter could not have been written without the help of Joyce White and Vincent Pigott, to both of whom go many thanks. We are grateful to Surapol Natapintu (see his 1982 thesis) and Christine Abiera for undertaking the metallographic studies under the direction of R. Maddin and Vincent Pigott.

2. The PIXE analyses were performed by S. Fleming, MASCA, University Museum, University of Pennsylvania, and C. Swann, Bartol Research Foundation, University of Delaware. For the technique, see most recently Fleming and Swann (1985).

3. As the tin content rises above about 11%, the beta phase begins to appear. A bronze with 24.8% tin, if quenched from above 520°C shows a preponderance of the beta phase. No beta phase or, for that matter, no decomposition products of the eutectoid beta phase were observed in the artifacts.

4. Recent fieldwork by the Thailand Archaeometallurgy Project, codirected by V. Pigott and S. Natapintu, is providing detailed evidence of just what types of copper ore were being exploited in prehistoric Thailand. Weathered copper sulfide ore deposits, with strong suggestions of the presence of native copper, and chalcopyrite have been recorded (Pigott and Natapintu, personal communication).

5. Differentiating decarburized cast iron from the normal bloomery iron on the basis of their microstructures is not at all certain, particularly when the decarburization occurs extensively. Chinese metallurgists studying early first millennium iron have concluded (Ko Tsun, personal communication) that the "bloomery" product was in fact decarburized from cast iron.

6. K. C. Chang (personal communication) believes that, although there may not have been *intensive* contact with south China, there was sporadic contact earlier than the first half of the first millennium B.C.

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16 Early East Asian Metallurgy: The Southern Tradition

Joyce C. White

The development of metallurgy can be addressed from several points of view, many of which are represented in this volume. One approach to the topic is summarized in the subtitle of a recent synthesis for a lay audience entitled *Out of the Fiery Furnace: The Impact of Metals on the History of Mankind,* by Robert Raymond (1984). Although a valid point of view not only for writers for the public but also for scholars, the book has latent biases and limitations. The underlying historical inquiry focuses on where and when certain developments that in hindsight have proved significant to the use of metals today came about. Data not fitting into some sort of a progression to today's use of metals may be treated covertly or overtly as less important or peripheral.

An inquiry on metallurgical development from the viewpoint of an anthropologist might focus on the hows and whys or what archaeologists like to call the "processes" of metallurgical development. The hows and whys of any expression of metallurgical use, and even nonuse, would be examined in the contexts of specific cultures. In other words, the anthropologist might ask, What was the impact of humankind on the history of metals?

Southeast Asia is a relative newcomer in the discussion of the beginnings of metallurgy. Here I try to place into anthropological perspective the general significance of the early metallurgy that has been found recently in Southeast Asia to the study of early metallurgy as a whole. In this discussion the phrase "Southeast Asia" will refer to mainland Southeast Asia, including the southern portion of China. The data with which I have firsthand familiarity are from northeast Thailand, particularly the site of Ban Chiang.

Over the past few years the chronology of Southeast Asian metals has undergone detailed reevaluation (Bayard 1984; Higham 1984; Higham and Kijngam 1984; White 1986). The current consensus on the dating of bronze and iron at least for northeast Thailand is that bronze appears around 2000 B.C., give or take a couple hundred years. Iron appears in the first millennium B.C. with some disagreement as to whether it appears before or after 500 B.C. These current best estimates are not to my knowledge seriously out of phase with the limited Southeast Asian evidence outside of northeast Thailand, primarily Vietnam. Readers interested in a detailed discussion of the chronology for the controversial site of Ban Chiang can see White (1986).

It should be emphasized that current chronological understanding is based on excavations of only a few sites and on minimal data on metals. Refinements, revisions, and amplifications should be expected in the future as archaeological research in Southeast Asia expands. I challenge those working in other areas to examine their chronological data with the detail and