Eyewitness Accounts of the Early Mining and Smelting of Metals in Mainland Southeast Asia

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In Southeast Asia, as in many other parts of the world, the student of premodern technology is not likely to find that much relevant data exists in indigenous historical documents. He must therefore adopt other approaches: studies of historical and archaeological objects in museums, excavations of early industrial sites, inferences from general theory, and comparisons with those traditional techniques that survived long enough to be recorded by outside observers.

The last of these approaches, the use of what might be called ethnohistorical analogy, is of particular importance in the study of ancient metal production, for here the conceptual gap between modern and early technologies is especially wide. A specialist familiar only with the metal making systems of the present day, carried out on a vast scale and using methods based on the developed theories of half a dozen sciences, is likely to have difficulty in comprehending the small-scale, rule-of-thumb methods of earlier times. He may have even more difficulty evaluating them. If he knows what to look for, laboratory analyses will help him to understand what could and could not be accomplished by preliterate technologists working with simple equipment. But no amount of excavation and laboratory work is likely to give him an idea of the social and economic parameters involved: the time and labor needed to perform a process, its efficiency when measured by the cost of labor and raw materials, the ways in which production might have been organized, and the effects that all this might have had on the larger societies within which all technological systems are necessarily embedded.

Archaeometallurgists—students of ancient metallurgy—therefore tend to be deeply interested in first-hand historical descriptions of traditional non-Western techniques for extracting and fabricating metals. They are particularly interested in descriptions by eyewitnesses who were knowledgeable about technical subjects. The ideal eyewitness would be a professional metal manufacturer, geologist or mining engineer with a command of the local language, a knowledge of the local culture, and the ability to write unambiguous descriptions of what he has seen. Such paragons did exist among Western and Western-trained travellers in various parts of the world during the 18th and 19th centuries. Unfortunately, they were very scarce in Southeast Asia.

Premodern metal production in East Asia, the Middle East and Europe has been extensively recorded, by outside and local observers and even by actual practitioners. In South Asia and Africa, most of the relevant data come from outsiders during the 19th and early 20th centuries. These data are abundant and (in the case of South Asia, at least) reliable. For both regions, the number of records of indigenous mining and smelting runs into the hundreds (see, e.g., the bibliographies in Cline 1937 and in LaTouche 1917–8). In Southeast Asia, by contrast, the total does not exceed two-score, and many of these tell us no more than that a particular metal was extracted at a given place during the time of the author's visit.

The reasons for this scarcity of published data cannot be gone into here. It is sufficient to say that local chroniclers and other writers were not interested in the subject, that most foreign travellers in Southeast Asia were neither interested nor technologically literate, and that indigenous metal-making there seems to have already been in decline by the time that the first interested outside observers came on the scene. One of the authors (Bronson n.d.) has argued elsewhere that Southeast Asian miners and smelters had long suffered from foreign competition, first from efficient Indian and Chinese producers and then from the explosively expanding technologies of the West. Tin was the only metal where Southeast Asia held its own, due to the impregnable advantage of possessing about two-thirds of the world's reserves of that metal. For local producers of iron, copper and the rest, however it had been centuries since commercial prospects were especially encouraging. In the face of severe and long-continued foreign competition, the mining and smelting of metals within Southeast Asia survived only where foreign technology, first Chinese and then European, could be easily adapted or where producers were sheltered by geographical barriers.

The few known eyewitness accounts of traditional metal making in the region are therefore precious. Those relating to Indonesia and East Malaysia have been collected and summarized by Marschall (1968) and by Harrisson and O'Connor (1969); between them, these writers describe about ten cases for which useful details exist, all of them relating to iron smelting in Borneo, Sulawesi and the Minangkabau area of Sumatra. We know of only one case that those writers missed: Abendenon's (1917–8: 1713) description of iron making by a Bugis-ToBada group at Soroako in eastern Sulawesi. We also know of two cases from the Philippines: Santos (Jagor 1875: 179–85) and Hernandez (Eveland 1905: 16–18) on copper smelting by the Kankanay of Mancayan in northern Luzon, and McCasky (1903) on iron smelting and casting by Chinese workers at Bulacan in central Luzon. These three examples plus those cited by Marschall and by Harrisson and O'Connor may close the list as far as insular Southeast Asia is concerned. We would be surprised if more than a handful of other cases were to be found in the literature.

The purpose of this article is to present the results of a first attempt at collecting as many cases as possible from the Southeast Asian mainland. The eleven accounts summarized here do not represent closure. We believe that a number of other descriptions exist in the geological literature on Burma and Vietnam. Moreover, we have deliberately left out Yunnan in southwestern China, which is not only in many senses a part of Southeast Asia but also the home of a highly developed and well recorded tradition of metal production: indeed, there are more good accounts of mining and smelting operations for Yunnan than for all other parts of mainland Southeast Asia combined. The availability of comprehensive summaries of these accounts (e.g., Tegengren 1923–4: 347–64; Brown 1920) makes it unnecessary for us to consider Yunnan in any detail here, but the proximity of the vast and sophisticated Yunnanese metals industry must constantly be kept in mind when considering premodern metallurgy in the rest of the region.

We do not claim that the data presented here relate to economic activities that were important to the region at the time they were practiced. They are in a sense no more than relics, obscure and small-scale technological systems that managed to survive, often precariously, down to the time when some outsider happened to notice them. Their importance lies in what they tell us about much earlier periods, when Southeast Asia seems to have been the home of a prosperous and even advanced metals industry. The remains of that industry litter the landscape of those parts of the region that were rich in ores and fuels, forming the subject of an increasing number of archaeological investigations. It is these investigations that the present article is meant to assist. Although the data are sparse, they show that a surprising variety of metals was made and that the processes used were by no means unsophisticated. Many elements of these processes are likely to turn up in future excavations.

What follows is therefore intended in part as an ethnotechnological handbook for archaeologists. For the sake of convenience, it treats the evidence relating to different metals separately, arranging the cases by date within the sections that relate to the appropriate metal. Only cases that involve actual descriptions are included. These are of two kinds: accounts where the writer is himself an eyewitness and accounts where the writer managed to interview former participants, checking their memories as far as possible by whatever furnaces and other metal-producing apparatus still remained at the time of his visit.

A certain number of interesting details will be underlined in the "comments" paragraph that follows each description. However, we have not attempted a full technical analysis, nor to follow up every trail that opened along the way. The data are presented as straightforwardly as possible, leaving it to others to explore their implications.

IRON MINING AND SMELTING 1860s

Thanbo and other villages, Mount Popa or Puppadaung, ca. 20 kilometers east of Pagan, central Burma. Personal observation by W. Blanford (quoted by Percy 1864: 270–3) and reconstruction using interviews and on-site study by H. L. Chhibber (1926: 219–32).

The mines are open quarries on the mountainside, yielding iron concretions from a clay matrix. The mineral is hematite with some limonite. Two samples tested by Chhibber showed low iron contents of 26.3 and 22.8 percent.

Smelting is done at various villages in the immediate neighborhood. The one visited by Chhibber still had 12 furnaces that were visible; Blanford implies that he saw similar numbers at one locality. Chhibber reconstructs these furnaces as "circular or oval pits 3–4 feet in diameter, dug in compact earth," as in a river bank, and "connected with a circular hole, a little more than a foot in diameter," which served for feeding the furnace with charcoal. He goes on to say "it is remarkable that they had no opening to provide a blast." Blanford describes quite a different type of apparatus: shaft furnaces about 3 meters high, with a rectangular cross-section and (like Chhibber's furnaces) dug into a bank that surrounds the shaft on three sides; the fourth or front side is walled in by a thin clay screen. There is a large opening to provide a blast, for—like many reported furnaces in Africa but unlike any others in Asia except for a single case reported from Yunnan by Moore-Bennett (Tegengren 1923–4: 352)—air was supplied by natural draft, not bellows.

Both Blanford and Chhibber agree about the general course of smelting: the furnace is filled with charcoal and ore and then lit; charcoal but not more ore is added during the smelting run. A furnace run continues until "the molten metal flows out by tapping the lower part of the furnace" (Chhibber) or until a solid bloom has formed on the bottom of the furnace, which takes about 24 hours (Blanford). No flux is used (Chhibber and Blanford). The bloom weighs about 20 kilograms (Blanford).

Although the smelters are part-time farmers, in their role as ironworkers they are specialists in the production of raw metal that is fabricated elsewhere. Their iron was formerly famous, being shipped throughout the lowland area of central and upper Burma. Production ceased in the late 1860s, shortly after the British annexation of the area.

Comment:

Blanford's description, though often quoted in archaeometallurgical writings, was evidently not known to Chhibber. Both were geologists in the employ of the Geological Survey of India. Chhibber was an old Burma hand; Blanford was not, but had seen and written about a number of traditional smelting operations in India. That he knew more about practical non-Western metallurgy is shown by the fact that he does not bother to say that flux was not used (it is almost never used in simple bloomery furnaces) and does not suggest that the iron might have flowed out as a liquid (which is highly improbable in a furnace of the low-temperature type he describes). Because his visit took place during the wet season, Blanford did not see the furnaces in operation either, but his account is circumstantial enough to make it clear that he had good informants. Chhibber's curious statement that the furnaces "had no opening to provide a blast" (a clear impossibility, as pointed out by Suchitta 1983) must represent a misunderstanding of what his elderly informants told him. They may have said that smelting was carried out, not without an air blast, but without bellows.

IRON MINING AND SMELTING 1860s

Near Loei, Northeast Thailand. Personal observation by H. Mouhot (1864: 133).

Mouhot does not describe mining directly but implies that the ore comes from "immense beds of magnetic ore of a remarkably good quality," found on a mountain in the Loei area.

The furnaces are holes "about a yard and a half square hollowed out close to the mountain." The mineral is piled up and smelted with charcoal. The "liquified iron" collects in a hollow in the furnace floor, whence it is withdrawn when the smelting session is completed. The iron, presumably in the form of a raw bloom, is then carried back to the village where it is worked up in a hearth described as a "cavity," supplied with air by a pair of upright piston bellows operated by a child.

The same people do the smelting and smithing. They are not full-time ironworkers, being "half-agriculturalists, half-artisans." Their spades and cutlasses are shipped to all the surrounding provinces, "even beyond Korat."

Comment:

An explorer rather than an academically trained scientist, Mouhot was not knowledgeable about mining or metallurgy. Moreover, the published account was compiled without his supervision from the rough notes that survived his death in Laos, a few weeks after his visit to Loei. This may be why the account is incomplete. It says nothing about any bellows used with the smelting furnace, or about yields, smelting time or many other details that would be of interest. It is not in fact absolutely clear that Mouhot actually saw a smelting furnace in operation. In spite of its deficiencies, however, the report is important. It is one of the very few published descriptions of smelting in an area which on archaeological and geological grounds appears to have been one of the key metal-producing zones of ancient Southeast Asia.

IRON MINING AND SMELTING CA. 1880

Villages of the Kui, Cuoi, Khouy, etc. ethnic group, Phnom Deck range, Kompong Soai Province, Kampuchea. Personally observed by J. Moura (1883: 43–6) and by E. Fuchs and E. Saladin (summarized at length in Beck 1891: 1009–11).

Two kinds of ore are used, one called "heavy" and the other "light." The latter is preferred because of the hardness of the iron produced, which makes it suitable for weapons manufacture. Moura seems to say that the "light" ore is "very rich with a 65–66% metal content." Fuchs and Saladin cite a less impressive 35–40% metal content without mentioning that the Kui recognize two types of ore. The miners apparently do their own charcoal-making and smelting. The mines are in the Phnom Deck; smelting is done in the villages at the edge of the range.

Because of the expense, furnaces tend to be built by groups of villagers or even by several villages. Each is a long rectangle in plan, 9. meters wide, 2.5 m. long and about. 4 centimeters deep, made of clay mixed with white sand. The top of this shallow basin is open: its walls taper from 20 cm. in thickness at the base to about 5 cm. at the lip. The furnace proper rests on a solid stamped-clay pedestal that raises the bottom of the hearth 80 cm. above ground level. Both ends of the furnace basin are pierced with holes for tapping slag. Each of the sides has 26 holes with 26 tuyeres which project some distance into the furnace. All tuyeres on each side are connected by bamboo tubes to a common bellows. There are thus two bellows in all. Each has the form of a drum made of stamped clay about 50 centimeters in diameter, with a leather diaphragm attached at its center to a cord and a spring pole. The feet of three operators (to each bellows) press the diaphragm down, forcing air into the furnace; the spring pole pulls the diaphragm back upward when the operators step off, letting the bellows refill with air. Two high bamboo screens protect the operators from the heat of the open hearth.

About 250 kilograms of ore and 5–6 hectoliters of charcoal, arranged in layers, constitute the charge. Once lit, the fire is blown gently at a rate of 8 strokes per minute for the first eight hours, then blown at a more vigorous pumping rate for four or so hours more. One heat is finished per day, yielding 10–15 kilograms of iron.

The bloom then is worked up into half-kilogram bars with pointed ends (illustrated in Colquhoun 1885: fig 10). This is done in a separate hearth, blown with a pair of upright single-acting piston bellows (Moura) or a single horizontal double-acting windbox bellows (Fuchs and Saladin). The iron bars contain "mixed particles" of iron and steel but are otherwise to a high purity. They are highly prized by many peoples of the surrounding area. The bars are traded all over Cambodia, Annam and Siam. The Lao use them as money.

Comment:

This is the best description of traditional smelting we possess from Southeast Asia. Interestingly, the process is one of the most unusual. The furnace, clearly described by both sources, is unique among recorded bloomeries. The closest analogue is found in the *tatara* furnace of Japan, which is also long, narrow and furnished with rows of tuyeres along both sides, although it is much larger and produces a different kind of iron. The Kui bellows is unique in Southeast Asia (nothing like them is reported in Marschall's comprehensive 1968 survey) but is of a type common in Bihar and Orissa in eastern India, where clay drum bellows with spring poles and often with several operators per bellows were widely used by small-and medium-scale ironmakers of the preindustrial period.

The reason for the furnace design is not clear; one imagines that with a somewhat deeper basin and an excess of fuel, such a device might be able, like the *tatara* hearth, to produce a natural steel or even a mixture of steel and cast iron. The bellows is without question an import from India. The fact that the Kui were not in close contact with overseas areas at the time of Moura's, Fuchs' and Saladin's visit suggests that the importation may have occurred at a relatively early date.

IRON MINING AND SMELTING 1880s–1920s

Bo Luang (or Baw) Plateau, Chiang Mai Province, northern Thailand. Personal observation by A. R. Colquhoun (1885: 51); reconstruction using interviews and on-site study by E. W. Hutchinson (1934: 164–5) and by P. Suchitta (1983: 35–41).

The ore is mined at a deposit about 35 kilometers away. None of the sources describe the mines or mining procedures. The ore is "a red oxide" according to Colquhoun, but Suchitta was shown a sample that resembled magnetite. Women do much (or, according to Colquhoun, all) of the mining work. The mines are considered the exclusive property of Bo Luang village. The ore is carried there for smelting on elephants (Colquhoun) or on the backs of women and men (Hutchinson and Suchitta).

The smelting furnaces are cubical clay structures measuring two and one-half feet on a side (Hutchinson) or about one meter high (Suchitta). They are supported with wooden boards (Hutchinson) or a clay-covered bamboo framework (Suchitta). There are two large openings in the furnace, a 10–20 centimeter hole in the top and a 10–15 cm. hole in one side that served for extracting the bloom and, perhaps, for tapping the slag. A third opening admits the tuyere, which is loosely connected to the bamboo tubes that leads to pair of upright single-acting piston bellows. Suchitta suggests that the loose fit between the tuyere and the tubes may have made it easier to draw air into the bellows.

The size of the charge and smelting time are not given. Hutchinson notes that the "iron droppings from the ore are collected four times and returned to the furnace." Suchitta had a piece of old slag analyzed and found that it had a very low percentage of iron oxides (about 8% FeO and Fe_2O_3) which may confirm some recycling of slag, although Colquhoun maintains that the smelting method used is so "rough" that it "yields only fifty percent of the metal." The lump of iron that is extracted at the end resembles a small orange (Colquhoun). One such bloom that had been preserved as a keepsake was weighed and analyzed by Suchitta: it weighed 0.94 kilograms and contained 93.49% iron, 0.28% carbon, 0.02% manganese, 0.052% phosphorus and 0.004% sulfur; the rest was presumably slag.

The bloom seems to have been reheated and forged in the same furnace as that used for smelting, and the same individuals did at least some of the work. Although women did much of the mining and smelting, and although men must have done a good deal of the smithing, none of the sources suggest a rigid sexually-based separation of different parts of the process. The knives, bells, tongs, etc. thus produced were traded to the Chiang Mai area. Colquhoun says that in his day the village paid iron articles as tribute to the "Zimme chief," the governor of Chiang Mai. The tribute articles were elephant chains, spear heads, cooking pots and other ironware.

The inhabitants of Bo Luang are Lawas, a tribal people speaking a Mon-Khmer language. Their customers were northern Thais. Suchitta and Hutchinson imply that they were not full-time ironmakers. Colquhoun, however, says flatly that they also were not "agriculturists." All sources agree that the Lawa were large-scale raisers of livestock: cattle and, according to Colquhoun, elephants. They were rich in the latter animal.

Comment:

Between them, the three sources give a clear but somewhat undetailed picture. One is left with a number of questions concerning mining methods, ores, inputs, yields and costs. It would also be interesting to know more about the furnace used: in spite of its boxlike description it may just be an ordinary short shaft furnace with thick walls. One of the first writers to connect the Lawa with smelting (of lead, not iron) was Crawfurd (1828: 419); their propensity for metallurgy was widely known in the late 19th and early 20th centuries (see, e.g., McCarthy 1902: 120). The pattern of tribal peoples making iron for sale to state-organized peoples also appears in Cambodia (see the description of the Kui in this paper), in Borneo and Sulawesi, and in the Khasi Hills of northeastern India.

IRON MINING AND SMELTING 1890

Loi Nam Lin (Doi Nam Lin?), Lai Hka Circle, N. Pang Long State, eastern Burma. Personal observation by G. B. Stirling, quoted in full by Scott and Hardiman (1900: 299–301).

The ore was mined from three deep, narrow shafts and from a number of open workings on a hillside, apparently not far from Loi Nam Lin village. Formerly several villages worked at mining the ore, carrying it to be sold to the smelters at Loi Nam Lin. At the time of Stirling's visit in 1890, smelting was carried out only on a smaller scale. The smelters seem to have done their own mining by then.

The furnace is made of earth and has two large openings, a lower one for loading in charcoal at the start and an upper one for feeding in charcoal and ore, a handful at a time, while smelting is under way. The fact that (upright piston?) bellows of bamboo are used suggests that there is a third opening for the tuyeres. Nothing is said about tapping slag. Two men are needed to tend the furnace. Each smelting run, done only once each day starting at 2 am, lasts about four hours. A bloom made experimentally "in an improvised furnace" weighed about 5 kilograms.

Four blooms can be made in five days, the fifth being reserved for marketing. The iron is bought by smiths in neighboring villages in Pang Long but some goes to Mong Nai (Muang Nai) State. The products of the Pang Long smithies are well known. Some are shipped as far as Mae Hong Son and Chiang Mai in Thailand.

Comment:

No data are given about the nature of the ore, the size and form of the furnace, or many other details that are of interest. However, it is worth noting that ore and charcoal are fed in continuously. This implies that the furnace is of the shaft type; a yield of 5 kilograms in four hours suggests that is not very small: a height of 1.5–2 meters seems reasonable on analogy with Indian and African furnaces. The smelters appear to have been natives of the area; that Scott does not bother to identify them means that they are probably Shans. Scott and Stirling both regard the Loi Nam Lin system as a mere relic of the larger-scale system of production that existed before the British conquest and the introduction of cheap British iron and steel. Their opinion is in part confirmed by the evident capacity of the furnace. It they had done several runs per day, the two furnace workers would each have produced about 10 kilograms/day—a quite respectable level of labor productivity by preindustrial standards.

IRON MINING AND SMELTING CA. 1910

Uang Sa Pong (Wang Sapung), 26 kilometers S.E. of Loei, N.E. Thailand. Personal observation by Hogboom (1913–4: 78).

The mines, about 5 kilometers northwest of the village, are just "shallow diggings to get the loose pieces." The excellent hematite ore was analyzed at 68.5% iron, 0.042% phosphorus and 0.006% sulfur.

This was smelted at the village in small furnaces approximately one-half meter high, about which no further details are given. Although smelting had almost died out at the time of Hogboom's visit, the village still housed an important smithing industry, using imported English iron bought from Chinese traders.

Comment:

This very brief description is significant mainly because it represents one of the few cases where iron smelting in Southeast Asia survived into the 20th century. It is interesting to note that the village visited by Mouhot in the

Loei area also did both smelting and smithing. Judging from Mouhot's description of his route, the two villages are not the same.

IRON-ARSENIC MINING AND SMELTING
CA. 1910

Ban Hoei Tat, 40 kilometers north of Loei, N.E. Thailand. Personal observation by B. Hogboom (1913–4: 79–81).

The mine is on top of a mountain to the northeast of the village. The two diggings visible there are several meters deep and may be following a weathered vein of minerals. The ore was analyzed at 34.5% iron oxide (Fe_2O_3), 47.5% arsenic oxide (As_2O_5) and 16.2% water, with a little pyrite and traces of nickel and cobalt.

Smelting is done, apparently right at the mine, in "small furnaces sunk in the ground." The local people are aware of the poisonous character of the furnace fumes. No other details of the smelting process are given, but it is clear that the metal produced has a lower melting point than ordinary iron. Hogboom had a piece of the alloy analyzed. He reports the result as "Cu —93%, As —7%." The "Cu" here is evidently a printer's error; the alloy must actually contain 93% of iron and 7% of arsenic.

The local people "did not themselves know of any other use for the metal than casting bullets," but formerly traders from the South had bought it. Hogboom speculates that this may have been for making Buddha images.

Comment:

An iron-arsenic alloy like the one described would be easy to cast because of its low melting point but would be too brittle for most uses. The idea that it was used for casting religious objects is plausible; antimony alloys are known to have been used by northern Thais for similar purposes (see, eg, Gardener 1967: 1–2). What equipment would be needed to smelt such an ore is not clear. Deposits of iron and arsenic oxides are not common, and very few cases of smelting them are reported in the literature.

LEAD, SILVER (AND ZINC?) MINING AND SMELTING
CA. 1400–1850 AD

Bawdwin or Bawdwin-gyi, Tawng Peng-Loi, N. Shan States, N.E. Burma. Reconstruction using historical data and study of the site, abandoned 40 years earlier, by T. D. LaTouche and J. C Brown (1908: 235–63).

The gigantic deposit consists of galena and anglesite (lead sulfate) in more or less intimate association with zinc blende, along with lesser amounts of pyrite, chalcopyrite and silver. The silver content is variable but high. A sample picked up in 1900, 400 years after the richest deposits began to be cleaned out, showed 88 ounces of silver per ton of ore; run-of-mine ore in the 1920s and 1930s still averaged 18 ounces/ton (Bender 1983: 178). Certain ores with a very high zinc content appear to have been avoided by the early miners. LaTouche and Brown suggest that it was not possible to smelt these by the methods then available.

The mines consist of large numbers of shafts, galleries and open cuts that honeycomb the sides of a valley for a distance of about five kilometers. At least one such gallery cuts through solid rock for several kilometers. A number are wide and high enough to admit pack animals (mules, according to Scott 1900: 303). Galleries and tunnels are skillfully cut although rarely supported with timbering. Many were still in good condition at the time of the authors' visit.

Smelting took place in large open hearth furnaces, thought to have been without bellows, composed of a deep fire chamber in front and a sloping, bowl-like reduction space in back which was heated from beneath by flues. The liquid metal trickled out of the bowl and fell down through the fire chamber to be collected in a hollow at the bottom. LaTouche and Brown do not speculate on the reason for using such a furnace, although Brown comments that the process involved was clearly of the "roast and reaction" type—that is, a smelting procedure where lead sulfide is roasted to an oxide which in turn reacts with and decomposes more sulfide. Brown, an authority on Chinese metallurgy, notes that he has seen no furnaces like these in Yunnan.

Cupellation, separating the silver from the lead, is believed to have been accomplished in two stages, the first in round beehive-shaped furnaces and the second in square furnaces enclosed in stone buildings, presumably for security. The lead oxide or litharge left over after the extraction of the silver was probably resmelted to metal: none of the sources mention finding large quantities of litharge. The slag resulting from the initial smelting, however, had a very high lead content. Between 1909 and 1919 a British firm recovered more than 180,000 tons of old slag at Bawdwin; this had an average lead content of 60 percent (Bender 1983: 176) but a silver content of only 1.7–1.8 ounces/ton (Brown 1917).

Mining at Bawdwin is thought to have begun by AD 1412, the date of a Chinese inscription found there. All miners and smelters were Chinese, although some lead smelting by local Kachins, using the same lead slags as the later British company, took place there in the late 19th century. Crawfurd (LaTouche and Brown, p. 236) heard in 1827 that the mine produced 960,000 ticals weight of silver annually and that it employed 1,000 miners. Oldham (1855: 345) puts the number of miners at 10,000.

Comment:

No one who had worked at the mine, which closed in the 1860s for uncertain reasons, seems to have been still in the area at the time of LaTouche's and Brown's visit. Their reconstruction of processes is therefore based on educated guesswork, supplemented by the small amount of existing historical information. Both of the authors, on the other hand, were exceptionally knowledgeable about Asian ethnometallurgy. Their guesses are likely to be fairly close to the truth. As noted above, they do not speculate about the reasons why the unusual smelting hearths were used, but Brown's comment about a "roast and reaction" process may provide the clue. While such processes were notoriously inefficient in extracting lead, they were economical of fuel and were capable, if properly run, of extracting virtually all of the silver originally present in the ore. This would seem to have fitted the needs of the Chinese smelters perfectly. Fuel was scarce, and the distances involved would have made it very expensive to transport the lead to any market able to absorb such massive quantities of that metal.

Interestingly, although Scott (1900: 304) felt that the mines probably had been exhausted by 1860, they were reopened in 1914 and are still in operation. In the mid-1930s Bawdwin was producing 70–80,000 tons of lead annually, along with an equal quantity of zinc and perhaps 175,000 ounces of silver (Bender 1983: 178). As noted above, run-of-mine ore during this period still had an average silver content of 18 ounces per ton. This would have been a "payable" but not spectacular ore in the eyes of most preindustrial silver miners. On the other hand, if the ores exploited during the 15th–19th centuries resembled the 88 ounces/ton sample picked up in 1900, Bawdwin would have been one of the largest producers of precious metal in Asia.

LEAD AND SILVER SMELTING 1865

Kyaukthat, Yawng Hwe State, S. Shan States, E. Burma. Personal observation by Fedden, quoted in full by Scott and Hardiman (1900: 403–2).

Nothing is known of mining operations, as mine locations were kept secret. At the time of Fedden's visit in 1865, the ore was brought to Kyaukthat where it was sold to smelters. The ore is a lead mineral, presumably galena, with an unspecified silver content.

After it is crushed, the ore is put into a small "cupola or blast furnace" made of clay two and one-half to three feet in height and 16 inches in diameter. The air blast is supplied by women standing on raised platforms, presumably using the usual upright paired piston bellows; each furnace has two such women.

The reduced lead is ladled out (of a receptacle at the bottom?) and transferred in ingot form to small "reverberatory" cupellation furnaces. These consist of a fire chamber separated by clay bars from the molten metal below. As the lead oxidizes, "it is removed by gently revolving over the surface an iron rod around which the lead in the form of litharge (ie, lead oxide) accumulates in a number of coatings or layers, one upon the other." The relatively pure silver that remains in taken out as a button or plate from the bottom of the furnace. The "rollers" of litharge are then resmelted and the lead metal sold.

Comment:

As in other cases where Scott does not specify an ethnic group, the smelters here are probably Shans. It will be noted that several features of this particular method of cupellation, including the clay bars and the litharge "rollers," should be identifiable archaeologically.

LEAD AND SILVER MINING AND SMELTING 1890s

Maw Son or Bawzaing, Myelat District, S. Shan States, Burma. Personal observation by J. G. Scott (Scott and Hardiman 1900: 301).

The mines are on a hillside one mile northeast of Maw Son village. They are shaft mines, most or all of which "descend to about 300 feet before the miners follow up any veins." The lead ore (galena?) is argentiferous but averages only five rupees weight of silver per 365-pound basket. Mining tools are "a small hand pick, a mallet and a cold steel chisel. Two men take it in turns picking at the rock, while others carry the ore to the surface." There it is sold to the smelters, who carry it back to their furnaces in Maw Son.

Each furnace has a daily capacity of about five baskets of ore (about 1825 pounds) but is not further described. Unlike their counterparts at Bawdwin, the smelters of Bawzaing were not interested only in the silver in the ore. Scott says "the main profits were derived from the sale of lead."

Comment:

If, as Scott seems to imply the miners involved are Shans, this makes Bawzaing the deepest mine known to have been dug by native Southeast Asians before modern times. The furnaces might be vertical shaft furnaces or might be one of several types of open hearth; that they are of medium size is shown by their daily capacity of nearly one ton of ore. The silver content of the Bawzaing ores is indeed not high as such ores go; Bender (1983:182) says that ores mined there in modern times average only 10 ounces to the ton of 50–55% concentrate. That such ores could be mined economically implies a good market for lead, a low-valued metal, and hence cheap transportation. Bawzaing is not far from Taunggyi and the main overland trade route to Chieng Mai.

LEAD-TIN ALLOY MINING AND SMELTING 1890s

Benang Sta (Setar), near Biserat, Pattani River, Pattani Province, S. Thailand. Personal observation by H. Louis (1894: 235–6).

The ore occurs in the neighborhood of ordinary tin and galena mines but is, Louis says, "quite unique, as far I know, in the world. It has been produced by the gradual degradation of cassiterite-bearing granite and of limestone containing pockets of galena"; the result is what the author describes as a natural "pewter mine" with ores composed of oxidized lead minerals (anglesite with cerussite, pyromorphite and mimetite) intimately mixed with tinstone. The deposit is mined by sluicing away the overburden, breaking out the ore with crowbars, crushing it with stone-headed tilt hammers worked by human foot power, and washing until a sufficient concentration is reached.

Smelting is done in small blast furnaces about seven feet high. The product, "besides a good deal of lead fume, is a natural alloy of lead and tin." A coin said to be made of this metal was analyzed. It showed 69.4% lead, 27.9% tin, 0.7% iron and 2.0% "impurities."

The miners and smelters are Chinese. They sell the alloy "to the rajahs of the surrounding states, who use it to make the small coins called *pitis*."

Comment:

Mixed lead-tin deposits are not ordinarily considered to be smeltable. In this case, however, the original lead sulfide (galena) had been altered by weathering to a mixture of lead sulfate and carbonate, which can be reduced to metal in the same way as a tin oxide (cassiterite) ore. There must be at least a few other deposits of this kind in the cassiterite-and galena-bearing areas of Southeast Asia. The blast furnace and tilt hammer represent imported Chinese technology, but there is no reason why such ores could not have been handled with less sophisticated equipment in earlier periods. In Kedah, pewter *pitis* coins go back to the early 17th century; they were widely used in Kelantan, Pattani, and Trengganu in the late 18th century and afterward (Show and Kassim Haji Ali 1971). Considering that those kingdoms had much tin and little lead, and thus no incentive to make artificial tin-lead alloys, it seems possible that even the earliest pewter used in *pitis* was a natural alloy made from an ore similar to that mined at Benang Setar.

As we said in the introduction, we do not intend to discuss all of the implications of these eyewitness accounts for archaeology and history, However, a few points are worth emphasizing.

WOMEN, MAGIC AND METAL MAKING

It is common in other parts of the world to find that mining and smelting operations are surrounded with elaborate taboos and ritual practices.

In Africa, taboos against women at mining, smelting and smithing places were (and still are) very widespread. The mere appearance of a woman at a smelting furnace often meant that work had to stop and that lengthy special ceremonies had to be performed before smelting could resume. In Europe and the Middle East, explicit taboos connecting women and metal working seem to have been rare, but the idea of a women acting as a smelter or smith was almost as inconceivable as in Africa.

Nothing like this is reported in Southeast Asia by any of our sources. Among the Lawa, women not only engaged in all phases of metal making but, according to Colquhoun, monopolized some of them. He says all smelting was done by women. A girl made iron blooms for her marriage dowry, and continued to be in charge of smelting the ore mined by herself and her husband throughout her married life.

The other sources do not say

specifically that discrimination by sex in metallurgy is either present or absent. However, the fact that none of them mention it can be taken to mean that it was weak or absent in the places they wrote about. Suchitta (1983) cites other Thai cases of women engaged in metal working. It seems valid to conclude that in the ancient Southeast Asian mainland women were not usually barred from smithies and smelting places. They must sometimes have run those places themselves.

None of the sources says much about metal working magic either, although that topic is very important in writings on traditional metallurgy in Africa, ancient Europe, Indonesia and even China. Smelters and smiths in the mainland portions of Southeast Asia undoubtedly performed magical ceremonies to ensure that their work would come out well. But the fact that the sources pay little attention to these ceremonies may imply that they were less conspicuous and perhaps less essential than in other regions.

ETHNICITY AND METAL PRODUCTION

Because the metal making operations that survived long enough to be seen by outside observers were usually in isolated areas, it is not surprising that the metal makers involved often belonged to minority ethnic groups. What is surprising, however, is to find these tribal metal makers selling their product to peoples with more developed economic and political systems.

That the Shans controlled some of the most important lead-silver deposits in Southeast Asia explains why they could produce and sell these metals to the Burmese and Thais. But what about the Lawa and Kui? Usable deposits of iron ore are present almost everywhere in Southeast Asia. So why should the northern Thais, Laos and Cambodians buy iron from backward tribal peoples instead of making their own?

We cannot offer a fully satisfactory explanation. As noted previously, a number of other tribal groups in Asia were formerly successful exporters of iron—the Khasi in northeastern India, the Ngaju Dayaks of Borneo, and the Toraja and ToBada of Sulawesi. All of these, like the Lawa and Kui, formerly smelted substantial amounts of iron for sale to consumers in economically developed areas.

Part of the explanation may lie in superior ores. The Kui, for instance, had access to exceptionally good iron deposits in the Phnom Deck mountains. Yet there is no suggestion in the sources that the majority of successful tribal smelters utilized unusual ores. Instead, the sources tend to imply that the tribal iron and iron implements were technically superior to those made by the majority ethnic groups. We must give serious consideration to the possibility that certain of the more "primitive" Southeast Asian peoples were in fact more technologically advanced than their civilized neighbors in terms of metal making and fabrication.

Perhaps the most interesting case is that of the Kui. They are thought to have inhabited their present homeland on the fringe of the Phnom Deck for many hundreds of years. The Phnom Deck is the largest (and highest-quality) deposit of iron ore in Cambodia. The smelting methods used by the Kui are complex and ususual, involving the use of one item of equipment—the spring pole-operated drum bellows—that was definitely borrowed from India, presumably at an early date.

What this adds up to is a fairly strong argument for the idea that in former times the Kui were important suppliers of iron to Angkor. We do not know whether there is epigraphic or other direct evidence for this. But we do think it quite possible that weapons supplied by the simple Kui were a key factor in the military success of the greatest of ancient Southeast Asian empires.

COPPER

Copper, important as a metal in its own right and also as the chief ingredient of bronze and brass, is naturally of great interest to archaeologists. It is therefore unfortunate that no outsider ever seems to have seen and written about traditional copper mining or smelting in the non-Chinese parts of mainland Southeast Asia.

The well-recorded historical Yunnanese copper industry (many references are given in Brown 1923) is not precisely relevant to our understanding of early copper smelting in the area south of Yunnan, for during the 17th–19th centuries the copper mines and smelting plants of that province were among the largest in the world.

The previously mentioned records of tribal copper smelting at Mancayan in the northern Philippines therefore have special importance. They represent the only case of the mining and smelting of copper by a Southeast Asian people to have been observed and described in print. Interestingly, the Kankanay smelters at Mancayan employed a notably complex method for extracting metal from the local arsenical copper sulfide ores.

We might note that Jagor's and Eveland's descriptions of Kankanay smelting are good. They are worth studying by anyone interested in the Southeast Asian Bronze Age and in the more general problems of preindustrial technology. Rather similar ores are found in several parts of Thailand, Burma and Vietnam. Some archaeologists have assumed that such ores would have been avoided in antiquity because of the difficulty of smelting them. And yet the Kankanay, whose material culture is otherwise quite simple, appear to have handled those ores competently. It is entirely possible that methods as sophisticated as those of the Kankanay were known at an early date elsewhere in Southeast Asia.

OTHER TOPCS

A number of important subjects have not been touched upon in this concluding section: the capacity of furnaces; the productivity of labor; the geographical distribution of techniques; the locations of mines and smelters with reference to markets and sources of raw materials; the unusual number of natural alloys produced by traditional Southeast Asian smelters; the existence of specialization in producing raw metals as opposed to finished metal goods; and so forth. Most of those subjects would require many pages to discuss properly, and such a discussion might be premature in any case.

The reason why a discussion might be premature is that new information is now coming in from archaeologists at an increasing rate. A new generation of specialists, some with extensive training in the techniques of the metallurgical laboratory, have become interested in the study of early Southeast Asian metals. Excavations focussed on archaeometallurgical problems have begun to be carried out—for instance, Piggott's and Natapintu's as yet unpublished work at Phu Lon in northeastern Thailand. We therefore expect that within the next decade our views on early Southeast Asian metal production will have changed drastically. Much of what we now think we know will have changed drastically. Much of what we now think we know will prove to be incorrect. New interpretations, some of them still unimaginable, will replace those of the present day.