Notes on The History of Iron in Thailand

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INTRODUCTION

When a general history of the use of metals in Thailand is written, the chapters on iron are likely to focus on two topics. One of these has already aroused lively interest among archaeologists and historians of technology: the question of the date when iron in Southeast Asia first came into use. The other, though, scarcely yet recognized as a problem for research, is equally puzzling and interesting: the question of the date when and the reasons why the original one-stage or "direct" process of ironmaking was replaced by the two-stage "indirect" process. The latter appears to have been unknown in Thailand during the periods usually studied by archaeologists. Yet it was dominant there by the time that historical sources first took notice of such things. In the 17th-18th centuries, the complex but efficient indirect ironmaking process was still unknown in most parts of the world. There were only three exceptions: Western Europe, Eastern Asia, and Thailand.

This paper essays a preliminary treatment of both topics. The first section discusses the earliest iron in Thailand and neighboring regions. The second outlines the distribution of and the technical differences between the direct and indirect processes, suggesting that in its preference for the former, early Thailand is more like South Asia and the Middle East than like China. The third presents archaeological evidence indicating that the direct process was the only one known in Southeast Asia in ancient times. The fourth presents historical evidence showing that a change had occurred by the 17th or 18th century, that ironmakers in Thailand (but not in the rest of Southeast Asia) had shifted to the indirect process. The fifth and last section summarizes the preceding sections and considers a few possible explanations for this minor but significant industrial revolution.

1. THE EARLIEST IRON

Most researchers are now agreed that iron came into use in mainland

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Southeast Asia a thousand years or more after the appearance there of locally made copper and bronze. Most also agree that iron antedates the advent in the region of substantial Indian or Chinese influence, which does not become evident before 100 BC-AD 100. Higham (1983:7) accepts a 400 BC date for the earliest iron in Northeast Thailand on the basis of radiocarbon dates from the site of Ban Chiang Hian. Kijngam (1983:10) uses the same evidence to suggest a date of 600 BC. Bayard (1984:6) notes that several radiocarbon dates and no fewer than ten thermoluminescence (TL) dates on objects from Northeast and Central Thailand place the beginnings of the use of iron in the first half of the first millennium BC.

A number of researchers, however, are skeptical about the validity of the TL method as applied to objects made and preserved under Southeast Asian conditions. It is therefore of interest of interest to note that a good many new C-14 dates have recently been made available. These, along with the ones published previously, are listed in Table 1.

TABLE 1. RADIOCARBON DATES EARLIER THAN 500 BC FOR IRON IN THAILAND

Site	Province	Date BP	Date BC (cal.)	Lab. No.	Ref
BAN CHIANG	* Udon Thani	3610 + 230	2315 - 1710 BC	P - 2247	1
NON NONG CHIK	* Khon Kaen	2900 + 120	1320 - 1010 BC	R - 2809/9	2
BAN CHIANG	* Udon Thani	2830 + 50	1115 - 875 BC	P - 2455	1
BAN CHIANG	Udon Thani	2780 + 50	930 - 825 BC	P - 2634	1
BAN PUAN PHU	Loei	2680 + 210	1105 - 745 BC	P - 2939	1
BAN TONG	Udon Thani	2670 + 170	915 - 765 BC	P - 2723	1
NON NOK THA	Khon Kaen	2560 + 100	820 - 585 BC	GaK - 1028	3
BAN CHIANG	Udon Thani	2520 + 50	795 - 585 BC	P - 2665	1
BAN TAMYAE	Khorat	2520 + 130	820 - 415 BC	beta - 2757	4
NON NOK THA	** Khon Kaen	2480 + 80	790 - 415 BC	GaK - 1027	3
BAN I LOET	Loei	2460 + 200	815 - 390 BC	P - 2941	1
BAN PUAN PHU	Loei	2440 + 50	630 - 415 BC	P - 2938	1
DON KLANG	Khon Kaen	2440 + 50	630 - 415 BC	P - 2674	1
BAN CHIANG	Udon Thani	2410 + 210	800 - 375 BC	P - 2450	1
BAN TAMYAE	Khorat	2390 + 60	605 - 405 BC	beta - 2756	4

* = Date rejected by excavator (s) as implausibly early

** = Probably erroneous -- date refers to Historic Period context

References: (1) U. of Pennsylvania Museum, pers. comm.; for data on sites see Schauffler 1976, Gorman and Charoenwongsa 1976, Penny 1982 and White 1982; (2) Bayard 1979: 26; (3) Bayard 1971: 26-31; (4) D. Welsh, pers. comm.

The fourth column of Table 1 lists the dates in "calibrated" form--that is, as corrected for known long-term variations in the proportion of atmospheric carbon-14. The calibration used here represents the current best estimate of the true age of the samples in question. It will be seen that there are now fifteen dates, all on samples associated directly with iron or with types of artifacts found elsewhere in association with iron, which fall into the first half of the first millennium BC. These are supported by no fewer than twenty-seven more iron-associated dates between 100 and 500 BC which have not been listed here, from the above sites and from Non Chai in Khon Kaen, Ban Chiang Hian in Maha Sarakham, Non Khaw Wong in Chaiyaphum, Tham Ongbah in Kanchanaburi, Tha Muang in Suphanburi, and Chansen in Nakhon Sawan (see Charoenwongsa & Bayard 1983; Higham 1983; Chantaratiyakarn 1983; Bayard 1977:89; *Radiocarbon* 1970:587-8; Loofs 1979:346; and *Radiocarbon* 1973:111).

This steadily increasing number of early C-14 dates makes it easy to accept that iron in Thailand is sufficiently old to have been made and used there well before the period of the first intensive Chinese and Indian contacts, which cannot be much earlier than the 1st century BC. But a confident estimate for the very beginnings of local ironmaking cannot yet be made. The date one ultimately selects will depend on one's evaluation of the archaeological context of each dated carbon sample and, perhaps even more importantly, on one's feelings as to whether a given date for Southeast Asian iron is plausible in view of the history of iron elsewhere in the world.

The most serious critique of the contexts of many Thai C-14 dates has come from Higham (1983), who suggests that all such determinations should be discarded if the sample in question has not come from an ancient hearth or the equivalent so that the excavator can be absolutely certain that the carbon in the sample was not redeposited from earlier levels. Many of Higham's fellow archaeologists, however, feel that his criteria for a valid date are unnecessarily strict. While one or two dates on charcoal or other carbon-containing materials found outside hearths should naturally be received with caution, it seems improbable that substantial redeposition should be a general rule: that most carbon samples from most sites should at some point in their history have been dug up and then buried in the soil again. Unless evidence to the contrary exists, we should be safe in concluding that the majority of radiocarbon dates derive from samples which reached their final resting place in the soil no more than a few decades after the death of the plant or animal from which the sample came.

The other principal objection to an early dating for iron in Thailand stems from the feeling that metallurgical and other cultural developments there are unlikely to be earlier than similar developments in other places. Such objections are often advanced with regard to dates for Southeast Asian bronze. However, this does not appear to be a problem in the present case. Iron smelting in several parts of the Old World goes back well beyond 500 BC. In the Middle East and Egypt it was certainly known before 1000 BC; as Snodgrass (1980) and Pleiner (1980) show, iron had reached a position of real economic importance by 800-600 BC over much of the Middle East and southeastern Europe. In South Asia, in spite of a continuing scarcity of extensive series of dates from individual sites, there are a number of indications that iron appears at 700-800 BC and perhaps even earlier (Chakrabarti 1976, 1977). SubSaharan Africa as well has begun to produce moderately early iron dates. Short radiocarbon series from sites in Uganda in East Africa and from Nigeria in West Africa point to dates in the 4th or 5th centuries BC (Merwe 1980).

Iron in China is also relatively old. The art of smelting was discovered in that country in the 8th or 7th century (Li 1975), and its use seems to have developed from that point with extraordinary rapidity. By 500 BC, China possessed an iron metallurgy which was easily the most advanced in the world in terms of techniques and the scale of processing. By the beginning of the Han Dynasty in 212 BC, Chinese iron is thought to have been cheaper and more abundant than in any other economy of the period, while the technical sophistication of Chinese blast furnaces, foundries and fineries would not be matched even in western Europe for another 1600 years.

In fact, one of the few parts of the Old World where early iron has not been found and has rarely been claimed is insular Southeast Asia. There, metallurgy in general and ferrous metallurgy in particular still do not look much earlier than they did to prehistorians of Stein Callenfels' and Heine-Geldern's generation; no iron-associated materials with credible dates earlier than 100 BC have been found anywhere in Malaysia, Indonesia or the Philippines.

These late dates do not apply to the Southeast Asian mainland, however. Only two countries there have as yet seen substantial numbers of prehistoric excavations and radiocarbon dates: Thailand and Vietnam. In both, the art of smelting iron seems to appear at a moderately early date. Table 2 lists nine published radiocarbon determinations from Vietnam that point to the presence of iron before 100 BC. Although less information exists about their exact contexts than is the case for iron-associated dates from Thailand, most are accepted by outside specialists (e.g., by Higham 1983).

These Vietnamese data help to make it seem more plausible that the ancient inhabitants of Thailand began to smelt iron during the first half of the first millennium BC. The plausibility is increased by the abovementioned data from other regions. Although a few parts of the Old World--much of subSaharan Africa, northern Europe and insular Southeast Asia--appear to have had no knowledge of iron at the time, others certainly did, including central and southern Europe, northern Africa, southwestern Asia and much of East and South Asia as well. The accumulating evidence for a relatively early beginning of the Iron Age in Thailand need not astound us nor affront our sense of historical probabilities. If it should turn out that iron was in common use in Thailand by 500 or 600 BC, that still would show only a relative precocity. Other regions were much earlier in discovering iron and somewhat earlier in taking the more important step of using it in substantial quantities.

2. THE DIRECT AND INDIRECT PROCESSES

I do not propose to go into the question of whether the technology of smelting and working iron was independently invented in Southeast Asia or whether it was borrowed from outside. Hard evidence on the subject is still much too scarce for any worthwhile conclusions to be reached. However, one point relative to the origins of Thai ironmaking can be made with some certainty: wherever it came from, it was not borrowed from northern China. The reasons why are somewhat complex but are worth discussion, for this will clarify several technical issues and will thus set the stage for understanding the differences between the way iron was made in Thailand during the archaeological period and the methods of later times.

The first such issue to be discussed relates to the fact that until the mid-19th century most of the iron used in the world was of the low-carbon variety known as "bloom" or "wrought" iron. This is characterized by a high melting temperature, which makes it impossible to shape by casting; by relative softness and ductility at red or white heat, making it easy to shape by forging; and by relative toughness and low strength. A pure wrought iron contains almost no carbon and is in fact less strong and hard than many bronzes. However, it has two advantages over any bronze or other copper alloy: (1) because iron ores are very abundant, it is much cheaper, and (2) through adding some but not too much carbon by one of several methods it can be converted to steel, which in terms of combined toughness, strength and hardness is superior not only to bronze but to most other ancient or modern materials.

Low-carbon wrought iron and its derivative, steel, were the only types of iron used in most places for most of history. East Asia, however, began at an early date to employ a third type: the very hard, brittle and moldable high-carbon metal known as "cast" iron which, though a good material for making objects like kettles and stoves, is unsuitable for functions requiring shock resistance, as in axes or swords, and which cannot be shaped by forging. The methods of handling cast iron seem to have been unknown to the other technologically advanced nations of antiquity, giving China a world monopoly of making it for perhaps a thousand years. The technology of cast iron was picked up by the Koreans and Japanese sometime in the early first millennium AD and by Central Asians several centuries after that; it was not learned by Europeans until about AD 1300. And yet even in China the market for a brittle, castable iron was limited. As in other countries a great deal of the iron used by the Chinese was of the forgeable wrought variety.

The second issue concerns the way in which forgeable iron is made, for it can be obtained through either of two processes. One is the socalled "direct" process that was preferred by early Europeans, Africans, and most Asians. A mixture of iron ore and fuel (generally wood charcoal) was heated at a relatively low temperature until a solid lump or "bloom" of iron formed at the bottom of the furnace. When this bloom was extracted and hammered while still hot until most of the slag was squeezed out, the result was a piece of low-carbon metal ready for immediate use by a blacksmith.

The other method for making a low-carbon wrought iron, the "indirect" process, appears to have been used in early times only in China and, later, in Korea and Japan. As its name implies, the process involves more than one stage. The ore and fuel (either charcoal or mineral coal) are first heated, generally in a larger and taller furnace than that used in the direct process, to a temperature high enough actually to liquify the iron, causing it to run out of the furnace or to collect at its bottom as a molten pool that solidifies as a piece of brittle cast iron with a very high carbon content. It is of course possible to remelt this type of iron and to pour it into molds then and there—the techniques and temperatures needed for molding cast iron do not differ greatly from those needed in casting bronze. However, assuming that a softer and more malleable metal is wanted, it is necessary to put this high-carbon cast iron through a second processing step in a second furnace. This "fining" step involves reheating the iron until it again becomes a liquid and then exposing it to oxygen for long enough to burn most of the carbon out, yielding a solid mass of low-carbon wrought iron which is almost indistinguishable from iron made by the single-stage direct process and which is capable of being used in the same ways.

Why the complex and seemingly wasteful two-stage method should have been preferred in ancient East Asia lies outside the scope of this paper. It is enough for now to say that the indirect process was more efficient in some ways, that the large blast furnaces involved were capable of turning out much more metal in a given period of time than the smaller bloomery furnaces used in the direct process, and that at the present day almost all ironmakers use two-stage processes not greatly different in principle from that invented by the early Chinese.

The third technical issue to be raises related to the fact that the Chinese not only were the first to succeed in handling cast iron and in converting this to wrought iron but that they may never have known any other method. They were certainly using the indirect process by 500 BC, and many specialists in Chinese archaeometallurgy are of the opinion that this goes back to the very beginning of iron metallurgy there in the 7th or 8th century BC. The current consensus is that the earliest iron to be smelted in China was probably of the cast variety and that the art of removing the carbon from this must have followed shortly thereafter. Some specialists are not convinced this is true. However, until now no secure archaeological evidence has come to light showing that an ordinary type of direct-process ironmaking ever existed in those parts of China anciently inhabited by Chinese.

One reason why this conclusion is important is that it excludes northern and central China from consideration as a major influence on early ironmaking in Southeast Asia. As will presently be shown, Thailand and its neighbors made no use of the indirect process until two thousand years after they learned the art of smelting iron. The bloomery furnaces used by early Southeast Asians must have been quite similar to those used in many other parts of Eurasia and Africa. From a purely technological standpoint, such furnaces could have been introduced from any of those areas or, alternatively, could have been independently invented. But we may be fairly certain that the bloomery did not come to Southeast Asia from the North.

The archaeological evidence for the bloomery and the direct process in early Southeast Asia is presented in the next section. The sections after that return to the problem raised in the introduction, that of the eventual replacement in Thailand of the direct by the indirect process during the late historic period.

3. ARCHAEOLOGICAL EVIDENCE FOR THE DIRECT PROCESS

That the direct process was the only method of ironmaking known in ancient

Southeast Asia cannot be proved absolutely. This is strongly suggested, however, by the fact that no examples of cast iron or of the kinds of slags typical of blast furnace smelting have been found at any early site in the region.

Analyses of iron objects dating from late prehistoric, protohistoric and early historic phases at various Southeast Asian sites have been published by Suchitta (1983), Bennett (1983), Maddin et al. (1977), and Sieveking (1962:96). All of the objects in question appear to be made of typical bloom/wrought iron or heterogeneous mild steel. Although Sieveking *(ibid.)* states that the sockets on certain West Malaysian tools were formed by casting, the analysis he cites for one of these tools shows that the metal involved is a low-carbon iron which could not have been melted or shaped in a mold.

These analytic conclusions are backed up by a much larger number of visual inspections carried out by many archaeologists, including the present writer. One indeed cannot always tell by looking at a given piece of rusted iron whether it has been cast or forged. And yet in many cases one can, either because a shape is too complex to be formed by forging or because the object is of a type--for instance, a sword or knife--that could not function if made of brittle cast iron. I have not myself seen or talked to others who have seen a single object that was clearly of cast iron from any ancient site in Thailand, Malaysia, Indonesia or the Philippines.

The apparent fact that cast iron is rare or absent falls short of proof that the indirect process was unknown, for it is nearly impossible even with exhaustive laboratory tests to distinguish low-carbon iron made in a single-stage bloomery from that made in a two-stage blast furnace and finery. Although it seems somewhat improbable, one can still imagine an early technology in which all cast iron produced was promptly converted to wrought iron, leaving no cast ingots or other products behind to be found by archaeologists. It is therefore desirable to seek a less ambiguous kind of evidence.

The best evidence of this sort has to come from analyses of slags, the often glassy residues of smelting which represent various non-volatile components of the original ores, furnace linings, fluxes and fuels. Fortunately, slags from bloomeries and from blast furnaces can be easily distinguished. While the former contain a great deal of iron (generally in the 30–50% range) in the form of ferrous oxide, the latter under ordinary conditions contain almost no iron at all. Very few analyses of early iron smelting slags from Southeast Asia yet exist. Harrisson and O'Connor (1969, 1:190-5) report the compositions of single samples found by them and by Hutterer at several sites of the late first and early second millennia AD in Sarawak and in Luzon. Suchitta (1983) lists more detailed analyses of fifteen samples from eleven sites in Thailand, most with estimated dates earlier than 1000 AD. All samples in both groups show iron contents in the 30–50% range and are thus almost certainly not from the type of smelting furnace associated with the indirect process.

True, the fineries used in converting cast to wrought iron can also produce high-iron slags, and so can furnaces for smelting copper when, as was often the case in early times, iron ores are mixed with copper ores to serve as fluxes. However, the authors of both of the above studies feel that most of the slag they have studied comes from furnaces employed in the smelting of iron. There is no reason to question this. While a great many more analyses of iron objects and slage would be needed to establish beyond doubt that the indirect process was completely unknown in ancient Southeast Asia, it at least seems safe to conclude that direct ironmaking methods were much more common.

One part of Southeast Asia may prove to contradict this conclusion. Northern Vietnam, which was economically integrated with China for the whole of the first millennium AD, could obviously have shifted over to Chinese methods of ironmaking at a relatively early date. I do not know whether documentary or physical evidence exists for this. Considering that the one-stage direct process is not known to have ever been used by ethnic Chinese in China, it seems likely enough that early Chinese migrants to northern Vietnam would have brought their two-stage ironmaking methods with them. Moreover, it is possible that the indirect process was known in Vietnam before the Han Dynasty conquest of the late 2nd century BC. This is suggested by a statement of Tan (1980:131), who says that finds made at the Dong Son period site of Go Chien Vay included not only bronzes but objects made of "fonte", the technical French term for cast iron. It this proves not to be just a slip of terminology and if the objects in question are not Chinese imports, the Go Chien Vay finds would have substantial importance in the history of Southeast Asian metallurgy.

4. HISTORICAL EVIDENCE FOR THE INDIRECT PROCESS

The only other data we possess on premodern Thai ironmaking comes from a much more recent period, that of European contact. By then a major change appears to have taken place. Where previously iron had been smelted in small bloomery hearths, it was now made in blast furnaces operated by locally resident Chinese and presumably of traditional Chinese type. Pallegoix (Dasse 1976:142,161) and Bowring

(1977, I:235-8), writing in the mid-19th century, say that substantial quantities of cast iron were produced. Twenty years earlier Crawfurd (1967:408-9, 418-9) noted that a picul of local cast iron cost only half as much as as a picul of wrought iron in Bangkok markets, a fairly clear indication that an indirect process was employed to make the latter from the former.

Sewell (1922:13) quotes Prince Damrong as saying that Rama III began the casting of iron cannon in Thailand after observing that local Chinese artisans regularly cast large iron cauldrons. Pallegoix (Dasse 1976:141-2) includes both "iron" (presumably wrought bars) and "cast iron jauches" (cooking vessels) on his list of Siamese exports of the 1850s. Crawfurd (1967:409, 414, 540, 543) makes it clear that this cast iron found a substantial foreign market. In his day, in 1820, pans and other vessels of iron were regularly exported from Thailand to Vietnam, Cambodia and Singapore, whence Bugis traders reexported them to much of eastern Indonesia.

This success in the export business during the early and middle 19th century is somewhat surprising, considering that this was the period when cheap European-made cast iron goods had become dominant in most world markets. Moreover, the kinds of cast iron objects Thailand was exporting had long been a specialty of the efficient and competitive traditional iron industry of China. As late as the 1760s the government of King Taksin is known to have ordered several hundred large cast iron pans from China, and in earlier centuries these Chinese-manufactured pans were a staple of Southeast Asian trade. An anonymous author believed by Anderson (1981:424) to be George White, the brother of the famous Samuel, observed that in the 1680s iron pans were imported to Ayutthaya from Canton and Macao. The published 17th century *Daghregisters* of the Dutch East India Company (see, e.g. Chijs 1893:41, 50; Fruin-Mees 1928:678, 810, 927) contain numerous mentions of iron pans as part of the cargo of junks sailing from Chinese ports. Tome Pires (Cortesao 1944, 1:125) notes that quantities of iron kettles, bowls and basins went from China to Malacca in the 16th century. Fei Hsin (Mills 1970:120) refers to Chinese iron exports in the 15th century. Chou Ta-Kuan (Pelliot 1967:64) in the 14th century and Chau Ju-Kua (Hirth and Rockhill 1911:84, 160) in the 13th century include iron vessels -- almost certainly of cast iron -- in their lists of Chinese goods sold in Southeast Asia.

Withstanding the new European competition on the one hand and breaking the ancient Chinese monopoly on the other was therefore no mean achievement for the fledgling Siamese iron industry. That Thailand could sell cast iron pans even in places like Vietnam, right on the border of China, indicates clearly that its smelting and manufacturing methods had reached a very high level of efficiency. Yet it is also quite clear that this success in producing high-technology exports had been attained only recently.

Suchitta suggests that King Taksin's need to import cast iron pans in the 1760s arose from the dislocations to local industry caused by the Burmese wars, implying that ironworkers in Thailand were normally capable of making such things themselves. This may well have been the case: it is difficult to believe that the cast iron technology of the early 19th century could have been born and reached maturity within only a few decades. A beginning as early as 1700 is therefore quite plausible. On the other hand, White's testimony about the importation of Chinese pans in the 1680s comes from a period when Thailand was prosperous and relatively peaceful. We may perhaps conclude that if a locally-based cast iron industry existed during the late 17th century, it was not yet capable of fully supplying local needs.

The question is whether such an industry did exist at that date. A good many Western sources of the 1500s and 1600s note that Thailand produced iron and steel. Notices of this kind are usually perfunctory, taking the form of comments that Siam has mines of tin, lead, iron, steel and other minerals (e.g., Mendes Pinto 1653:177; Purchas 1968:569; and Valentyn 1726, 6: 1). These authors do not imply that the Siamese iron industry was especially important.

Only a handful of these earlier sources give more substantial information. White (Anderson 1981:424) states that iron, presumably of the forgeable rather than cast variety, figured among the *exports* of Thailand to the Philippines in the 1680s. On the other hand two writers earlier in the same century, Baldaeus (Anderson 1981:41) and Floris (Moreland 1934:78) imply that in their day iron for forging was regularly imported to Tenasserim and Ayutthaya from southern India. Floris actually participated in this trade, in 1613 carrying 300 *candy* (about 80 tons) of iron to Ayutthaya from Masulipatam, the chief seaport for the famous iron and steel-producing areas of Golconda.

Thus, Thailand appears to have been importing iron in the early 17th century and to have been exporting it only a few decades later. The situation becomes even more puzzling when the testimony of two other sources is considered, that of the reliable, well-informed La Loubere and that of Salmon and his Dutch translator, van Goch.

La Loubere (1693:15, 70) says that in the 1680s iron was mined in several parts of Siam. However, he says this metal was not wrought iron, maintaining that the

Siamese only "make use of iron as it is cast, by reason that they are bad forge-men." He repeats this criticism on a later page. Van Goch adds a similar comment to Salmon's (1730:471) description of Siamese products, saying "They have iron mines, which iron they know how to cast. ... Whatever is made by them, they are poor smiths, having neither nails nor pins, spikes or cutting blades; however they make spikes of bamboo."

These statements clearly require explanation. On a priori grounds it is difficult to accept that all Siamese forgemen of the 17th century were bad at their job. Competence in forging iron is so widespread among traditional metal workers in southern and eastern Asia that one would question La Loubere's and van Goch's opinion even if Thai museums did not contain numerous well forged objects of iron and steel dating to the 19th century and earlier. And yet La Loubere in particular is not a source to be disregarded without good cause. If we accept that his opinion was based on experience and that many forged iron objects in his day were indeed unsatisfactory, we must try to find another explanation. The only one that makes sense is that it was not the forgers but the iron itself that was at fault.

The idea that 17th century Siamese wrought iron was often of poor quality would explain the fact that Floris could make a profit by importing wrought iron (of notably high quality) from southern India to Siam, and might not contradict reports that Siamese iron during the 17th century was sometimes sold to the Spanish in the Philippines, who were perennially short of iron (cf. Blair and Robertson 1905, 42:302-3; 50:107; 51:143, 191; etc.) and may have had to take what they could get. However, it is not yet clear why this should have been so. Can Siamese wrought iron really have been worse than that of other countries if Siamese ironmakers were already skillful enough to make cast iron?

The answer is that this is credible from a technical standpoint if we assume that in La Loubere's day the iron industry of Thailand had already started to change over to the indirect process. Iron made by the direct method, like that of Masulipatam in South India, tends to have good forging qualities. The low temperature at which smelting is carried out in bloomery furnaces means that few impurities are likely to enter the finished metal. By contrast, blacksmith's iron made by the indirect process is often not so satisfactory. The high temperatures necessary to liquify the metal during the first stage of the process cause it to pick up impurities such as phosphorus that may be present in the ore and fuel. A metal of this kind may have good casting characteristics and thus be a desirable material from the standpoint of the foundryman. If converted to wrought iron, however, this same metal will often be brittle and difficult to handle in the blacksmith's forge. 17th and 18th century England offers a good example of this. England was a major producer of wrought iron by then. Its ironmakers already had two hundred years' experience with blast furnaces and fineries. And yet their product was widely considered to be of such inferior quality that large amounts of forgeable iron had to be imported from other countries. The British Admiralty, for instance, continued until almost 1800 to specify that the iron used in anchors, where phosphorus-induced brittleness was an especially serious flaw, should be either direct-process iron from Spain or indirect-process iron from Sweden (Wertime 1961:122, Schubert 1957:313).

Thus, La Loubere's criticisms of Siamese smiths may simply reflect the fact that the local iron industry was going through a technological transition. Although it may have begun to utilize blast furnaces by the 17th century, there is no reason to think that it would quickly have mastered the difficult art of converting this to wrought iron. A possibly similar situation appears to have existed in the Philippines in the 18th and 19th centuries, when Spanish entrepreneurs on several occasions tried setting up ironworks using Chinese laborers and techniques. As the Jesuit authors of the *Colleccion de Datos* (Anon. 1900, 2:299–300) comment, these produced excellently cast plough shares, kitchen utensils and cannon but, due to a lack of capital and "facultative knowledge," no wrought iron at all. One of the last remnants of this effort is described by McCasky (1903): a small tilting blast furnace of Chinese type in Bulacan, Luzon. At the beginning of the 20th century this was still making nothing but cast iron.

The only other suggestion we have that Thai iron made by the indirect process may often have been of indifferent quality is the surprising success of the tribal iron industry of the Kui, in northern central Cambodia. The equipment used by the Kui, which included large foot-operated drum bellows of an Indian type and small direct-process smelting hearths, seems primitive. Yet as late as the 1880s, as both Moura (1883:43–6) and Fuchs and Saladin (Beck 1891:1009–11) affirm, Kui iron was famous over a wide region, being exported as far as Laos, Thailand and Annam. The case seems to be parallel to that of the above-mentioned shipments of Spanish iron to England in the 18th century: a forgeable iron made by the direct process remained competitive for many years with an undoubtedly cheaper indirect-process iron, presumably because the old-fashioned and inefficient bloomeries made a better product.

5. CONCLUSION

What can be known of the history of iron in Thailand does not need much space to summarize. The art of smelting it was probably discovered at some time in the first half of the first millennium BC. As was not always the case in other areas, in Thailand the new metal was accepted with alacrity. It had displaced bronze as a raw material for weapons and tools used in agriculture and forestry well before the end of the prehistoric Iron Age in 100 BC–100 AD. By then it appears to have been employed widely and in substantial amounts. Although alloys of copper and tin had been comparatively abundant in the Bronze Age and were presumably not scarce or expensive in later periods, iron proved popular nonetheless. It continued to be used in large quantities during the protohistoric and historic periods by most or all of the ethnic groups of Thailand.

All iron in those early days was smelted by the direct process in bloomery furnaces that were probably quite small. Whereas a few examples are known in India of direct-process furnaces with daily outputs in the 100 kg range, and in 17th–19th century Europe with outputs as high as 500 kg, the vast majority of ethnographically and archaeologically recorded bloomeries (including all of those in mainland and insular Southeast Asia) are much smaller, producing perhaps 10 kg of iron per day and measuring less than two meters in height. We may assume that most or all early smelting furnaces in Thailand were of this kind. Individual ironmaking enterprises were undoubtedly also small. Judging by what is known of historic bloomery operations elsewhere in Southeast Asia and India, no more than five or six persons would have worked at one furnace. These may or may not have been organizationally associated with the ten-odd persons needed for obtaining fuel and ore and the five-odd persons who would have forged the iron produced into saleable knives, spears, axes and so forth.

We have no indication as of now that any great changes in technology occurred during the first two thousand years of Siamese ironmaking. While it is plausible that production became more organized during times of political success and economic expansion, it is currently not possible to establish that smelting furnaces became larger and more efficient, that animal - or water-powered machinery was employed at ironworks, or that significant innovations occurred in secondary processing. No evidence exists for the production of crucible steels like the *wootz* of India or for the bewildering variety of indirect iron — and steelmaking methods known from traditional China.

No technology can remain completely static for two millennia. Yet it should be remembered that bloomery iron made and processed by essentially prehistoric methods was a satisfactory and even superior product. As long as supplies of charcoal and ore remained abundant, it is possible that neither political decision-makers nor producers had any motivation to seek a change. They might indeed sometimes have found a need for specialty weapons steels or cast iron vessels, but these could have been imported easily enough. The foreign trade partners of Thailand included at least two outstanding producers of special-purpose irons. The "wootz" steel of India had already come to dominate a large foreign market by the 7th or 8th centuries AD, and the cast iron vessels of China were exported on a massive scale by the 12th or 13th centuries. There may have seemed to be little point in trying to compete with producers like these.

And in any case, a revolutionary change did eventually occur: the introduction of the arts of smelting and founding cast iron and of fining this to wrought iron. It is not clear when the changeover from the old direct process began. On the basis of very slender documentary evidence, the preceding section suggests that the movement to the indirect process was under way by the late 17th century but that local ironmakers may not yet have mastered the last stage of that process, the conversion of cast to wrought iron. On somewhat better evidence it might also be suggested that for a century or two the new technology was oriented toward import substitution rather than toward exports. Only in the early 19th century does evidence appear for the shipment of substantial quantities of iron to foreign markets.

That this is a remarkable fact has already been emphasized. In most parts of the world during the 1820s and 1830s traditional ironmaking industries were in sharp decline under competitive pressure from the explosively expanding technology of the West. Yet in Thailand local ironmakers using methods which, if not precisely traditional were certainly non-Western, managed not only to hold their domestic markets but to expand into foreign ones in the face of both European and Chinese competition.

Another index of the success of this Siamese industrial revolution can be found in the early and almost complete disappearance of the old direct process in most parts of the country. The history of ironmaking in other regions would lead us to expect that substantial numbers of bloomery furnaces survived in remote areas until the 19th century. This was true in Africa, South Asia, Insular Southeast Asia, and even in southern and eastern Europe (cf. Cline 1937, Krishnan 1955, Marschall 1968, and Beck 1893-1901), where scores or hundreds of bloomeries lasted long enough to be recorded by European observers. This was not true, however, in Thailand or neighboring countries. The ethnohistoric literature on Thailand itself contains very few mentions of direct-process smelting; the only case I know of is that of the Lawa, who continued to mine and smelt their own ore until the 1920s (Yule 1857:91, Hutchinson 1934, Suchitta 1983). Reports of bloomery furnace operations are similarly scarce for adjacent countries. The Kui appear to have been the only Kampucheans who were still smelting their own iron in the 19th century. I have found no eyewitness account of iron smelting from either Laos or West Malaysia, and only a few such accounts from Burma (LaTouche 1917: 248-51; Blanford in Percy 1864:270-3; Chhibber 1926; Scott 1900:299).

The relative absence in Thailand of furnaces using the direct process by the time European observers came on the scene is almost certainly a consequence of the rise of the indirect process and of a marked shift in the scale and pattern of production. During earlier periods, ironmaking in Thailand had been carried out by numerous dispersed productive units. Judging by the number of sites that contain slag and other smelting debris, smelting furnaces in the archaeological period were as widely diffused as in traditional Africa or India. In the late historical period, however, the number of ironmaking areas and presumably of furnaces underwent a very sharp decline at about the same time that the new ironmaking methods appeared. The new ironmaking enterprises were large and presumably efficient. It seems likely that this had the effect of driving down the price of forgeable iron. Eventually prices must have fallen so low that even distant and isolated ironworks using the old direct process could no longer compete.

Why the change to the new style of ironmaking happened when it did is not clear. The Chinese-style technology involved had long been in existence, and contacts between China and Thailand had been close enough since at least the 14th century for the necessary skills and technical advisors to have filtered through any barriers to technology export that Chinese governments might have imposed. One possibility is that the indirect process was indeed introduced at an earlier date; nothing in the evidence known to the present writer makes it impossible to believe that iron was being cast and fined on at least a modest scale in the Sukhothai or even Lopburi Periods. Another possibility is that the communications and markets in those earlier periods were not yet sufficiently developed. Without secure transport and large concentrations of customers, the scale economies inherent in medium-sized and large blast furnaces would not give the new process any advantage over the older bloomery methods.

A third possibility is that the explanation lies partly outside the realm of economics. The appearance in eastern seas of warships armed with cheap and effective cast iron cannon, which should have happened shortly before 1600, must have caused considerable interest among the rulers of those Asian states where, as in Thailand, bronze and brass were far more expensive than iron. Although Rama III is credited with establishing the first official foundry for iron cannon in the 19th century, it seems likely enough that earlier kings and other officials saw the potential military advantage of encouraging Chinese and other immigrants to enter the cast iron smelting business. Some may also have appreciated the desirability of being able to substitute local products for imports. This might have seemed particularly desirable with respect to products which, like cast iron pans in sugar — and salt — making, had important functions in other industries.

It seems pointless to speculate further. Hard data on many of these subjects undoubtedly exist, in local and foreign historical records and in the ground at archaeological sites. Quite possibly much of what has been said in this paper will prove to be untrue once those data are found, and it is certain that a great deal will have to be modified. The disciplines of economic and technological history are still very young in Thailand. The work of connecting them, of understanding how the one has affected the other in past times and how these in turn relate to sociological and environmental factors, has hardly begun.

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TABLE 2. VIETNAMESE C-14 DATES FOR IRON BEFORE 100 BC

Site	Province	Date BP	Date BC (cal.)	Lab. No.	Ref
CON CON NGUA	Thanh Hoa	2600 + 80	840 - 750 BC	ZK - 375	5
PHU HOA	Long Khanh	2590 + 290	1105 - 400 BC	Gif - 1999	6
PHU HOA	Long Khanh	2400 + 140	780 - 385 BC	Gif - 1996	6
GO CHIEN VAY	Ha Son Binh	2350 + 100	600 - 385 BC	Bln - 893	7
HANG GON	Long Khanh	2300 + 150	600 - 175 BC	MC - 62	8
CHAU CAN	Ha Son Binh	2325 + 60	430 - 390 BC	Bln - 1438	5
CHAU SON	Ha Nam Ninh	2285 + 45	415 - 380 BC	Bln - 1974	5
LANG CA	Vinh Phu	2235 + 40	405 - 185 BC	Bln - 1733	5
HANG GON	Long Khanh	2190 + 150	415 - 20 BC	MC - 61	8
LANG VAC	Nghe An	1990 + 85	165 BC - 60 AD	ZK - 310	5

References: (5) *Khao Co Hoc* 1977, 2: 87; (6) *Radiocarbon* 1974: 56; (7) *Radiocarbon* 1978: 392–5; (8) *Radiocarbon* 1966: 290