ANNA BENNETT

SOURCES OF COPPER AND TIN ORES IN PREHISTORIC THAILAND*

Copper ores are comparatively common in the world and were used in the production of the earliest metal objects. Tin, however, the other essential component of standard bronze, occurs in only a few localities. The sophisticated Bronze Age of the Near East developed in a region where copper was available locally, but there are no known significant tin deposits. It is therefore thought that the development of a bronze technology, at about 3000 BC, must have coincided with the ability of Near Eastern civilisations to trade over considerable distances (Tylecote 1976, 8).

By contrast, in China, Ho (1975, 183-185) has tabulated eight known tin deposits and twenty-one copper deposits within a 300 km radius of the Yen-shih, Cheng-chou and Anyang, Shang Period sites. Southern China is even richer in deposits and today Yunan is the main source of China's tin and copper industries (Charoengwongsa 1977, 40). The availability of mineral resources would have encouraged and facilitated the establishment of an early bronze industry in China, which might have influenced neighbouring South-East Asia. However, South-East Asia itself, is one of the few regions in the world where copper and tin occur together in relatively close proximity, and it is thus theoretically possible that bronze metallurgy developed independently in this area.

Copper deposits in Thailand

The earliest metal-age sites which have so far been discovered in Thailand, are on the Khorat Plateau in the north-east of the country, and there can be little doubt that, by the first half of the second millennium BC, there existed in that area a sophisticated bronze-working tradition. The evidence for metal workshop activities, including the alloying and casting of artefacts, has been well documented, but there is no evidence of copper smelting in the area. Unless fuel was in short supply, smelting would normally have been carried out close to the ore source and the Khorat Plateau is, in fact, devoid of base metal ore deposits. In an attempt to identify possible sources of copper ore for the ancient inhabitants, it is necessary therefore to consider the surrounding area. Geological Survey Reports provide details only of copper ore deposits which are of commercial potential. Small deposits might however have provided suitable ore sources for ancient metallurgists and archaeological surveys to locate such sources are therefore of importance. Today deposits with 0.5% or less copper are exploited, but ancient man is unlikely to have smelted ores containing less than 20% copper. Ores were won by open-cast excavation, which could be extended by underground tunnelling.

The provincial Geological Survey Reports for Thailand record deposits of chalcopyrite ($CuFeS_2$) which has a theoretical composition by weight of 34.5% Cu, 30.5% Fe, 35% S, and is often associated with pyrite (FeS_2) and pyrrhotite (FeS); chalcocite (Cu_2S) (79.8% Cu, 20.2% S); bornite (Cu_5FeS_4), which

* This work was carried out under a post-graduate scholarship from the British Academy. Additional financial support was provided by London University. I am most grateful to my supervisors Dr. I. C. Glover and Dr. N. Seeley for their help and encouragement throughout this study. The material was kindly loaned by the Fine Arts Department of Thailand. Bhuthorn Bhumathon (Lopburi National Museum), Surapol Natapintu (Central Thailand Archaeological Project), Colonel Monchai (Central Air Force Base, Lopburi), Dr. V. Piggot (University of Pennsylvania), and Udom Theetiparivata (Department of Mineral Resources, Thailand), provided invaluable assistance during periods of fieldwork. Help with the operation of analytical equipment was given by Ian Young (University College London), Kurt Kunzmann and his staff (Degussa, Frankfurt), Hennie Niebhaus (Bochum University), and Andreas Ludvi (Bochum Mining Museum). I also thank Professor H. G. Bachmann (Degussa Precious Metals Refinery, Frankfurt), Dr. A. Hauptmann (Bochum Mining Museum), Dr. R. Clough, and Professor I. Keesmann (Mainz University) for many useful discussions. I am especially grateful to Professor Bachmann for reviewing the manuscript.

also contains significant proportions of iron (63.3% Cu, 11.2% Fe, 25.5% S); malachite ($CuCO_3.Cu(OH)_2$) (71.9% CuO, 19.9% Co_2, 8.2% H_2O), and azurite ($2CuCO_3.Cu(OH)_2$) (69.2-4% CuO, 25.6% CO_2, 5.2% H_2O). Native copper has also been found as small pieces dispersed in weathered rock and in irregular masses or plates (Brown et al. 1953. – Sampattawanich and Ungkatawanich 1975). Copper mineralisations have been reported in the North-Eastern provinces of Nakhon Ratchasima, Loei and Petchabun; in the Northern provinces of Chiang Mai, Chianrai, Lamphang, Nan, Phrae, Uttaradit and Tak; in the Central province of Lopburi and in the South-Eastern provinces of Chachoengsao and Chantaburi (Sampattawanich and Ungkatawanich 1975. – Charoengwongsa 1977, 41-42. – Tantisukrit 1978. – Bunopas 1980. – Nakornsri 1981).

It is known that at Chantuk, in the province of Nakon Ratchasima, there is a narrow copper vein 11 km in length (Sampattawanich and Ungkatawanich 1975). The Department of Mineral Resources in Thailand (DMR) carried out core drilling at this site in 1943 and identified chalcocite, chalcopyrite and their derivative products. The copper reserves were however estimated as being too low for commercial exploitation (Sethapret et al. 1943-44. – Sethapret 1944). An examination of this site was made during the present investigations. A narrow trench, marked by a change in vegetation from dry scrub to marshy ground, indicates the course of the copper vein. The trench was traced for several hundred metres in a north-easterly direction, after which the vegetation became impenetrable. A large number of ponds, scattered over an area of 10.000 sq. metres, provided further evidence of past mining activity. Each pond, representing a mined outcrop of copper ore, measured between 8 and 10 metres in diameter, and most of them had been back-filled when the local school was built a few years ago. On the banks of the remaining ponds, small fragments of copper carbonate ores and quartz were visible. A discussion with the son of a former miner from the nearby village of Kanongphra revealed that, until the early 20th century, open cast mining was carried out with pick-axes. The ore was mined at depths of between 16 and 30 metres, and the walls of the pits and trenches were reinforced with wood shuttering. The mouths of the pits were expanded to increase ventilation, but, even so, a miner could work in a pit for periods of only two to three hours. The ore was hauled to the surface in bamboo baskets and the metal was extracted on site by primitive smelting. Although no surface scatter of ancient ceramics was found at the site, there is a possibility that Chantuk was a source of copper in prehistoric times.

Other possible sources of copper ore for the prehistoric bronze-smiths of the Khorat Plateau exist in the province of Loei, which forms the north-western border of the Plateau, and which is known to be rich in ore reserves. A considerable number of old mining and smelting sites have been located by Udom Theetiparivata and these were shown to the author in 1986. Slag sites have also been recorded during survey work by Bayard (1980), Penny (1982), and Piggot, Natapintu and Theetiparivata (Piggot 1984). Although there is evidence of a protohistoric culture, using bronze and iron tools, at the southern end of the Loei valley (Bayard 1980, 17), the smelting sites which are derived from iron and lead smelting are predominantly from the late historic period. Descriptions of iron smelting during the last century in the Loei valley are given by Mouhot (1864). The copper deposits of potential economic importance today, are mostly large masses of low grade ores. Phu Hin Laek Phi mountain, 15 km east of Loei town, has proven reserves of 15 million tonnes of low grade copper-bearing tuff and porphyry, containing 1% copper, with further possible reserves of 50 million tonnes. At Phu Thong Daeng »copper mountain«, 2 km north of Phu Hin Laek Phi, is a similar deposit, also containing 1% copper, equivalent to a possible 13 million tonnes of metal (Sampattawanich and Ungkatawanich 1975). Small amounts of copper ore appear to have been mined in the past from shallow surface pits, although details of this activity are unavailable (Jacobson et al. 1969, 19; 29). On a recent visit, the author observed no evidence of ancient mining activities and it seems that neither of these deposits was sufficiently rich in copper to have attracted the attention of prehistoric man.

Although no evidence of prehistoric mining and smelting in Loei Province itself has so far been found, one prehistoric copper mine has been located in the adjacent province of Nong Khai (Yamniyon et al. 1983). Excavation of this mine, known as Phu Lon (Piggot et al. 1985. – Natapintu 1988) has revealed a series of shafts sunk into the metamorphic skarn. Hundreds of stone mining tools made of igneous rock and presumably selected for their hardness (Weisgerber pers. comm. 1985) were found in the shafts and littering the surface, and these would have been readily available from the bed of the Mekong River. Radiocarbon dates from charcoal in an ore dressing area, in the vicinity of the mine, provided calibrated dates of ca. 1000-420 BC (Beta 17051), 790-275 BC (Beta 17052) and 1750-1425 BC (Beta 17053) (Natapintu 1988, 113). Excavation of a test trench in this area revealed a single stratum filled with prehistoric cord-marked potsherds, hand-size hammer stones, crushed malachite ore and discarded rock matrix. Malachite appears to have been the main ore mined, although native copper may also have been exploited (Natapintu 1987, 28). Drilling by the Department of Mineral Resources has revealed over 10 metres in depth of mining rubble, covering an area of hundres of square metres, which suggests that the mine was in use for a considerable period of time. Test trenches, averaging 3-4 metres in depth, revealed alternate layers of rubble and clean sand possibly indicating some sort of periodicity in the mining activity (Natapintu 1987, 28) or flooding. In the lower levels, narrow winding shafts with occasional metal pick blade marks in the walls indicate a different mining technique to that used in the rounded galleries of the upper levels, where stone tools were used (Weisgerber pers. comm. 1985). Although no slag deposits have been found in the vicinity of this mine, two mould fragments, numerous crucibles, pieces of casting splatter and abundant charcoal have been recovered. Because of the absence of slag, Natapintu (1987, 29) has suggested that this debris was derived from the melting and casting of native copper, or from the crucible reduction of malachite. It is however probable that, as the mine is close to the Mekong River, any slag deposits associated with it have been removed by erosion. Piggot et al. (1985, 48), have pointed out that the river would have served as a major conduit for the movement of peoples and materials.

An alternative source of copper for the ancient prehistoric settlements in North-East Thailand is to the south-west of the Khorat Plateau in Central Thailand (Fig. 1). The area contains both copper and iron mineral deposits and, in recent years, increasing evidence of ancient mining and copper smelting activities in the neighbourhood of Lopburi town has been found. In 1984 and 1985 the area was visited in order to assess the most significant sites and to assemble samples of past metallurgical activities (Bennett 1986; 1988a; 1988b; 1989. – Natapintu 1988). The metallurgists were using an efficient and standardized process, employing a crucible smelting technology rather than the more usual method of smelting in shaft and bowl furnaces. The very large number of ingot moulds found, compared to the number of two piece moulds used for casting objects, suggests that the bulk of the metal smelted at the site around Lopburi was cast into small copper ingots for export to sites where bronze artefacts were produced.

A possible source of copper ore is a deposit on the slope of Khao Phra Bat Noi, a mountain which is at the edge of Khok Krathium military air field in the Lopburi province. The deposit consists of malachite and azurite in two subparallel brecchiated zones in the granite, which is capped by a limestone roof pendant. The lower zone of mineralization, which is about 6 m wide, strikes north and dips 45° west. The upper zone, which is of similar thickness, strike and dip, lies about 20 m vertically above it (Brown et al. 1953). The deposit was prospected in the early 1920's by a European company which sank a shallow vertical shaft. However, although abundant hematite was located, the tenor of the copper ore was low and the site has not been exploited. Evidence of these activities remains and debris, most of which is ironstone fragments 5 to 10 cm sq. is scattered over the hillside. Copper staining was observed on the surface and larger quantities were revealed when the rock was cracked open.

A very distinctive and well preserved copper mine has been located nearby in the Wong Prachan Valley. Near the top of Khao Phu Kha mountain (Fig. 2), which is inside the Lopburi air force base, is a large man-made cave with galleries, the walls of which are stained green. Historic period sherds and small pieces of malachite have been collected by the local air force officers. In 1982 the site, thought to contain Hoabinhian occupation, was excavated by Bannanurag (Glover pers. comm. 1984). However, only the main chamber of the mine was excavated, and as soon as it became apparent that this was not a habitation site, the excavation was abandoned. X-ray diffraction analysis of ore samples collected in 1984 from an exposed wall indicated that malachite and chrysocolla were among the minerals present. The ore often contains in the region of 10% copper, the remaining gangue being composed of the oxides of silica, iron and calcium with small amounts of aluminium oxide (Table 1). It is possible that the lens of copper mine-

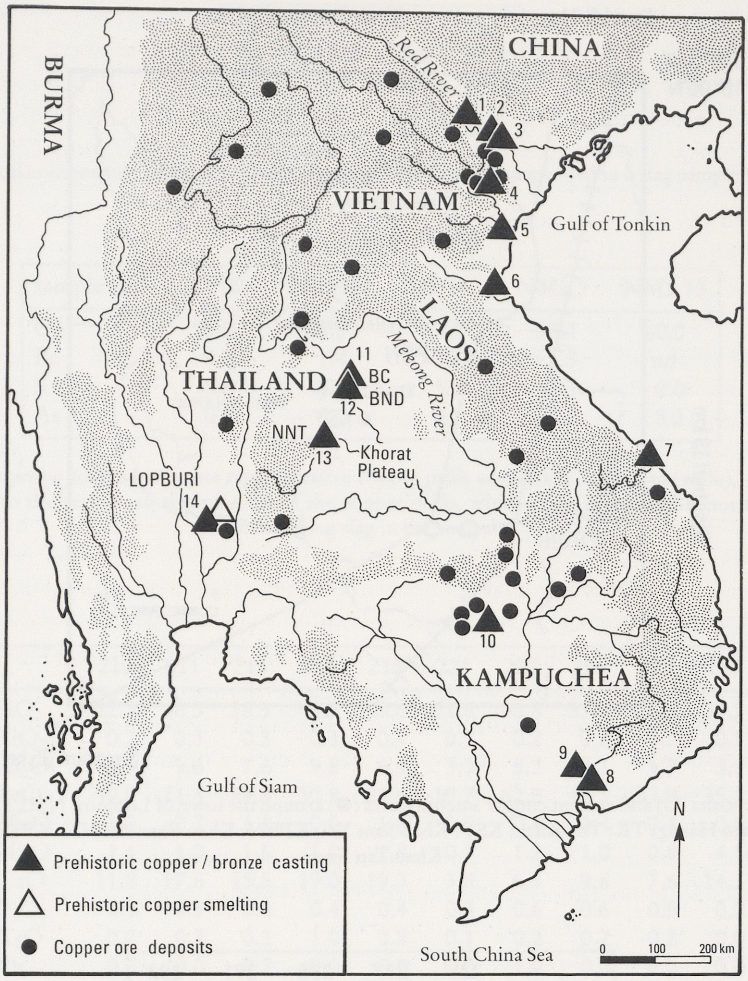

Fig. 1 Map of Mainland South-East Asia, showing the prehistoric sites at which bronze or copper was being cast and the principal deposits of copper. – 1 For Go Mun and Lang Ca. – 2 For Dong Dau, Doi Da and Thanh Den. – 3 For Co Loa and Dinh Trang. – 4 For Chien Vay and Dong Den. – 5 For Dong Son and Quy Chu. – 6 For Dong Mom, Xuan Giang, Ru Tran and Lang Vac. – 7 For Binh Chau. – 8 For Suoi Chon, Dau Giay, Hang Gon and Cai Van. – 9 For Doc Chua and Cu Lao Rua. – 10 For Opie Can and Samrong Sen. – 11 For Ban Chiang. – 12 For Ban Na Di. – 13 For Non Nok Tha. – 14 For Tha Khae; Non Mak La, Non Pawai, Nil Kam Haeng, Wat Tung Singto, Ban Klong Bamrung.

ralisation may have resulted from hydrothermal deposition within fractures or weak zones in the limestone (Sudham pers. comm 1987). The galleries are filled with small stones, and the site requires excavation to allow an understanding of the gallery system, the period of activity, and the presence of other copper bearing minerals.

At Khao Wang Phrachan (Fig. 2), a mountain 644 m high, in the same valley as Khao Phu Ka, the Department of Mineral Resources is known to have undertaken core drilling on the slope of the mountain, but the results were not published. Small amounts of copper staining are visible on outcrops of andesite porphyry and hornblende diorite, and it is possible that, in antiquity, surface mining took place at outcrops. Copper staining was also found associated with certain areas of the nearby iron deposits at Khao Tap Kwai which are still being mined today (Fig. 2). Malachite, azurite and chrysocolla have all been identified, and copper minerals seem to have been deposited within fissures in the dense iron oxide (Cremaschi pers. comm 1987). Chemical analysis of ore samples collected by the author at the site showed them to contain up to 28% copper oxide.

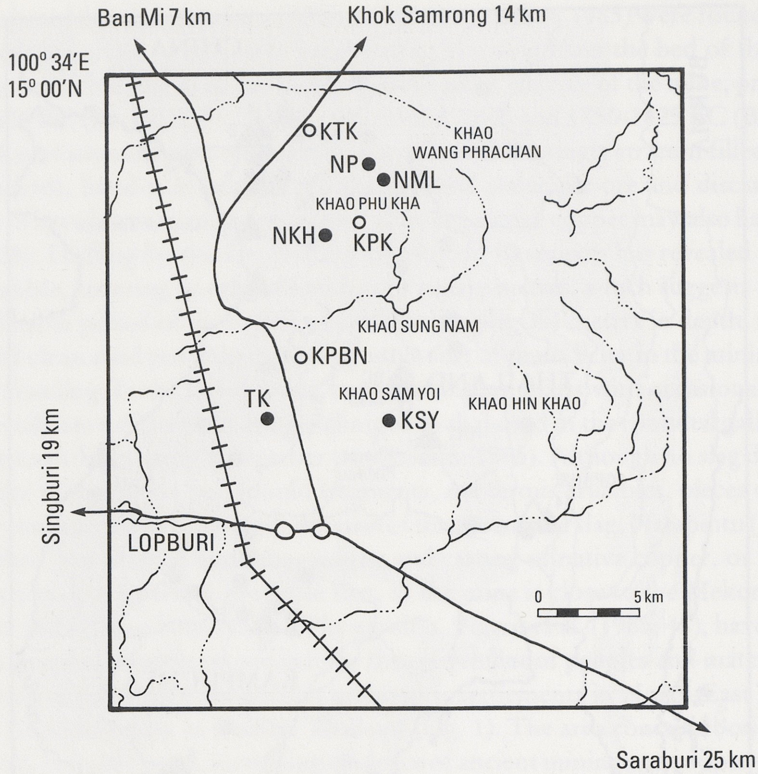

Fig. 2 Copper ore deposits (○) and ancient copper smelting sites (●) around the town of Lopburi. NML: Non Mak La; NP: Non Pawai; NKH: Nil Kham Haeng; TK: Tha Khae; KSY: Khao Sam Yoi; KPBN: Khao Phra Bat Noi; KPK: Khao Phu Kha; KTK: Khao Tap Kwai.

	228	237	238	291	292
SiO_2	35.1	30.6	38.4	51.8	2.4
TiO_2	0.0	0.2	0.1	0.0	0.0
Al_2O_3	4.2	4.5	6.7	0.2	1.0
FeO	22.9	21.0	18.3	7.2	94.0
MnO	0.5	0.6	0.5	0.1	0.3
MgO	0.1	0.2	0.6	0.0	0.5
CaO	32.0	24.3	25.7	0.0	0.0
P_2O_5	0.1	0.3	0.0	0.1	0.1
K_2O	0.0	0.0	0.0	0.0	0.2
Pb	0.0	0.0	0.0	0.0	0.0
Zn	0.0	0.0	0.0	0.1	0.0
Cu	1.4	11.6	3.0	22.4	0.2
S	0.1	0.3	nd	nd	nd

Tab. 1 Chemical composition of gangue and ore (wt%). – 228: discarded gangue mineral from Non Pawai; 237: sample removed from wall of copper mine at Khao Phu Kha; 238: gangue from copper deposit at Khao Pra Bat Noi; 291: ore from mine at Khao Tap Kwai; 292: ore from mine at Khao Tap Kwai.

It is noteworthy that the ore samples analysed did not include any sulphidic ores – although it is known from slag analysis, presented in Tables 2-4 that the prehistoric metallurgists in the area were using such ores, including arsenical copper minerals such as enargite (Cu_3AsS_4) and tennantite ($Cu_8As_2S_7$). This would have led to the accidental production of arsenical bronzes, which have superior mechanical pro-

Cu	32.5	57.9	75.1
Fe	31.5	15.5	2.9
S	30.1	26.9	22.2
As	0.1	0.2	1.3

Tab. 2 Chemical composition of three representative matte inclusions suspended in a slag sample (NP19) (wt%).

sample no.	NP 20	NP 19 b	NP 44	NML 3	NML 13
Cu	95.0	86.5	53.2	57.4	60.0
Fe	4.2	1.4	>3.2	>3.3	nd
S	0.0	0.1	5.5	0.3	0.0
As	0.4	0.0	3.8	4.9	5.3

Tab. 3 Electron microprobe analyses of some representative copper prills suspended in the slag (wt%). – (nd: not determined, the low totals are due to the very small size of some of the copper prills, which made it impossible not to include some of the surrounding slag in the analysis).

	210	211	213	214	215	221	222	224	225	227
SiO_2	32.3	46.3	38.3	45.3	45.6	21.6	30.8	31.4	26.3	34.2
TiO_2	0.2	0.3	0.3	0.3	0.4	0.1	0.2	0.2	0.2	0.1
Al_2O_3	6.3	9.6	7.6	9.8	9.9	3.3	5.2	4.1	4.7	3.1
FeO	40.0	21.4	89.4	30.9	21.4	19.7	62.0	48.3	53.9	35.1
MnO	1.0	0.7	1.1	0.6	1.0	0.5	0.4	0.4	0.4	0.6
MgO	1.4	1.0	1.6	1.0	1.8	0.7	1.2	1.0	0.8	4.1
CaO	11.8	17.6	15.5	19.0	19.3	3.8	6.5	9.8	7.6	14.3
P_2O_5	0.3	0.3	0.4	0.4	0.4	0.3	0.6	0.6	0.5	0.2
K_2O	0.2	0.3	0.2	1.0	0.8	0.1	0.2	0.2	0.2	0.0
Pb	0.0	0.0	0.2	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Zn	0.3	0.0	0.3	0.0	0.1	0.0	0.0	0.1	0.1	0.1
Cu	1.5	1.0	1.3	0.9	1.0	2.6	0.9	0.9	1.7	2.3
S	0.3	0.0	0.0	0.0	0.0	0.8	0.1	0.2	0.2	0.8

Tab. 4 Chemical composition of several representative copper slags from smelting sites around Lopburi (wt%). – 210-215: samples from Non Mak La; 221-227: samples from Non Pawai.

perties to artefacts of pure copper. The absence of sulphidic ores from the samples, all of which were collected from the surface, is undoubtedly due to the fact that surface deposits of sulphidic ores would have been oxidized by weathering. Moreover, ore samples containing low percentages of copper collected from smelting sites had almost certainly been discarded, and therefore do not necessarily represent the ore charge being smelted.

Tin sources in Thailand

In recent times, South-East Asia has produced the bulk of the world's tin, with an annual production averaging over 80 000 tons from Malaysia and 20 000 tons from Thailand (Penhallurick 1986, 68). Tin-bearing granite rocks extend from North Burma, through Thailand and peninsular Malaysia to the »Tin Islands« of Indonesia, covering a distance of more than 1800 miles (Hosking 1969; 1970). Today, approximately 94% of the tin produced in Thailand is from the southern peninsula. The central and western parts of the country yield only 4% and the remaining 2% comes from the north (Tantisukrit 1978, 783).

The most important tin mineral is cassiterite (SnO_2), which can occur as primary deposits associated with granitic rocks, and, in secondary deposits of alluvial and eluvial origin. The primitive method of separating cassiterite from these gravels is still continued by local miners today. The collected gravel is swirled in a pan, causing the lighter material to run off and leaving the heavy cassiterite and the associated magnetite, ilmenite, chromite etc., to collect in the pan as a black sand. On a larger scale, cassiterite may be collected by tin streaming and Raffles provides an excellent description of primitive methods still in use in the Sunda islands in the 19th century:

> »The process of mining in Banca is remarkable for its simplicity. It consists in an excavation made by digging perpendicularly to the beds of the ore, and a proper application of the water to facilitate the labours of the miners, and the washing of the ore. A favourable spot being selected, the pit is sketched out, a canal conducted from the nearest rivulet, and then the miners excavate the soil until they arrive at the stratum containing the ore, which is next deposited in heaps near the water, so as to be placed conveniently for washing; the aqueduct is lined with the bark of large trees, and, a stronger current being produced by the admission of more water, the heaps are thrown in, and agitated by the workmen; the particles of the ore subsiding through their gravity, and those of common earth being carried away by the current« (Raffles 1817, 192).

Placer mining of tin, leaves little evidence to which a reliable date can be attached and therefore little is known about the sources used by prehistoric man. A possible source of tin for the prehistoric bronze casters of the Khorat Plateau would have been the tin fields in Laos just across the Mekong river (Workman 1972), and in the Annamite Mountains bordering North-East Thailand and Vietnam. There have been reports that tin was mined and smelted in the 3rd and 4th centuries AD at Khwan Lukpad in Southern Thailand (Bronson in press). A Roman lamp has been located together with grinding stones, in a tin mine pit south of the present day Pilok Lead Mines in Kanchanaburi Province (Khun Kasset pers. comm. 1987) and in the past two years, the Archaeology Division of the Fine Arts Department in Thailand (pers. comm. 1987), has located at least three tin mining sites in Ratchburi Province of West-Central Thailand. Iron tools and incised bronze bowls from these mines are remarkably similar to those excavated at Ban Don Ta Phet, an Iron Age cemetery site dated to the 3rd century BC (Bennett, Glover forthcoming).

Summary

The Bronze Age metal working sites of Ban Chiang, Non Nok Tha and Ban Nadi are located on the Khorat Plateau, where no ore source is known to exist. However, there are tin fields in Laos just across the Mekong river and in the Annamite Mountains bordering North-East Thailand and Vietnam. These would have been potential sources of tin ore for the prehistoric bronze casters. Since the prehistoric bronze-casting sites are downstream from the Phu Lon copper mine, ores could easily have been rafted to some point downstream along the northern edge of the plateau and then carried a short distance overland to a smelting site near the village (Piggot et al. 1985). This ancient mine could thus have provided at least a significant part of the copper metal required by the metalworkers at Ban Chiang, Non Nok Tha and Ban Nadi. There is a gap in this evidence, since no smelting sites have been located either in the vicinity of the mine or on the plateau. On the other hand, during the Iron Age, large scale smelting activities were carried out in the Wong Prachan Valley in Central Thailand. There is limited evidence of early copper mining in this area, but it is quite possible that numerous small deposits have become exhausted during past centuries, since copper staining has been observed on outcrops. There is now evidence that copper and tin ore sources available in Thailand were exploited in prehistory. Evidence of Iron Age tin mining in Central Thailand is now also beginning to emerge. The fact that a hitherto unknown copper smelting technology was being employed by the first millennium BC supports the hypothesis that South East Asia may have developed a bronze technology independently from that of India or China.