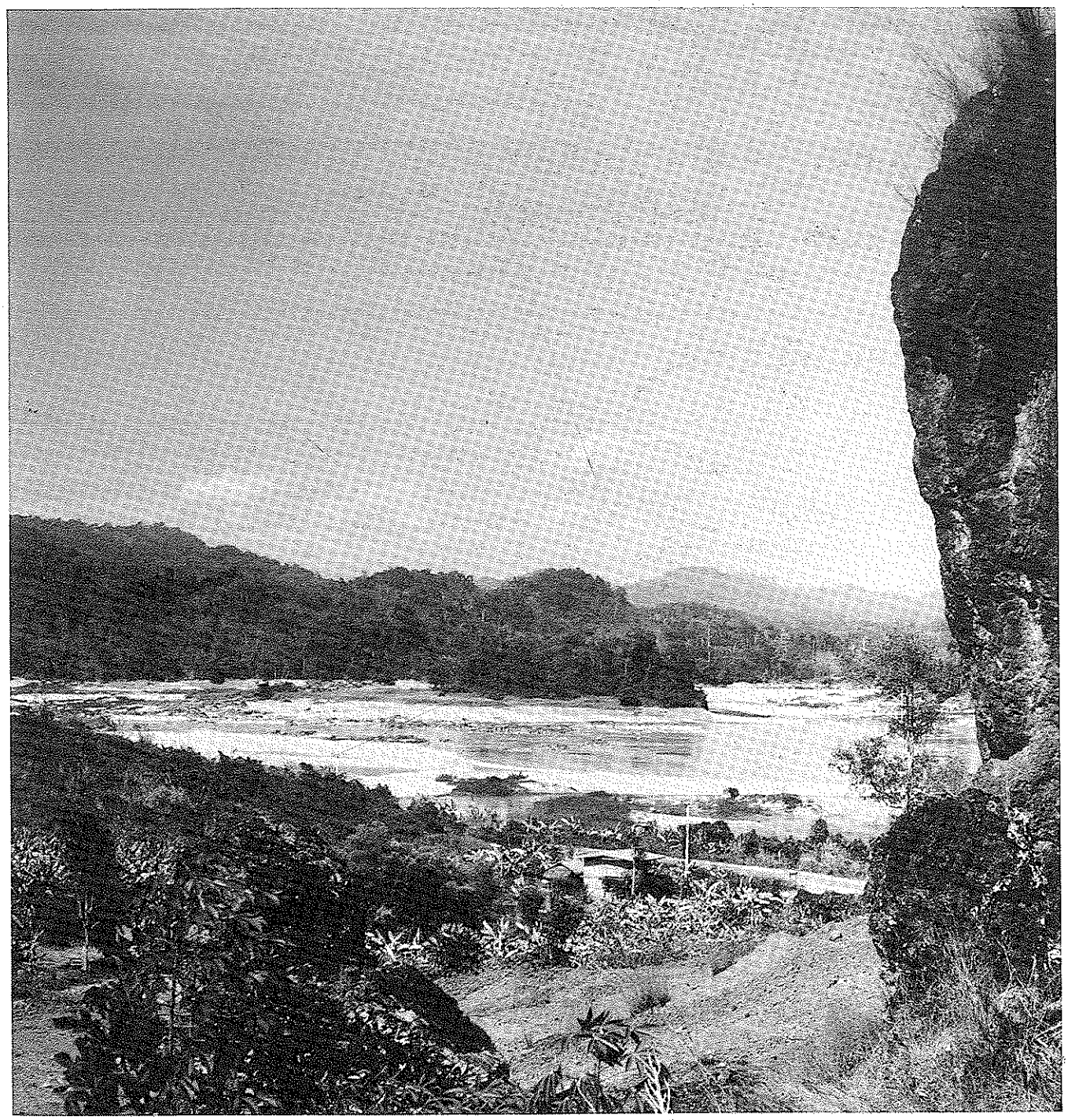
MASCA JOURNAL

1985

MUSEUM APPLIED SCIENCE CENTER FOR ARCHAEOLOGY
THE UNIVERSITY MUSEUM • THE UNIVERSITY OF PENNSYLVANIA
33RD & SPRUCE STS. • PHILADELPHIA, PA. 19104 • 898-4060 (Area Code 215)

Volume 3 Number 5 **Archaeometallurgy Supplement**



PRE-INDUSTRIAL MINERAL EXPLOITATION AND METAL PRODUCTION IN THAILAND

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Introduction

Stages I and II of the Thailand Archaeometallurgy Project (TAP) were completed in 1984 and 1985. This project, a combined effort of the Thai Fine Arts Department (FAD) and The University Museum, was organized to investigate systematically the evidence for pre-industrial mineral exploitation and metal production in Thailand. On the Khorat Plateau of Northeast Thailand several prehistoric sites have been excavated (including Non Nok Tha, Ban Chiang, Ban Nadi and Non Chai) which yielded archaeological evidence of copper/bronze production from *circa* 2000 B.C. into the late first millennium B.C., yet the Plateau now, as in antiquity, is a region virtually devoid of deposits of copper and tin. The question therefore arises as to the location of the ore deposits which provided the raw materials for the metalworking at the Khorat sites. The province of Loei seemed a strong candidate for a source area, since it lies just off the northwestern edge of the Khorat Plateau and is rich in mineral deposits, including sizable lodes of the base metals, copper, lead, and zinc.

Drawn by the richness and diversity of its mineral deposits, geologists have mapped and recorded the geology of Loei province quite extensively (Jacobson *et al.* 1969; Workman 1972; Jantaranipa *et al.* 1981). Meanwhile, archaeologists have conducted surveys directed at locating occupation sites along the major water courses of the region, the Mekong, Loei and Pa Mong Rivers (Bayard 1980; Penny 1982).

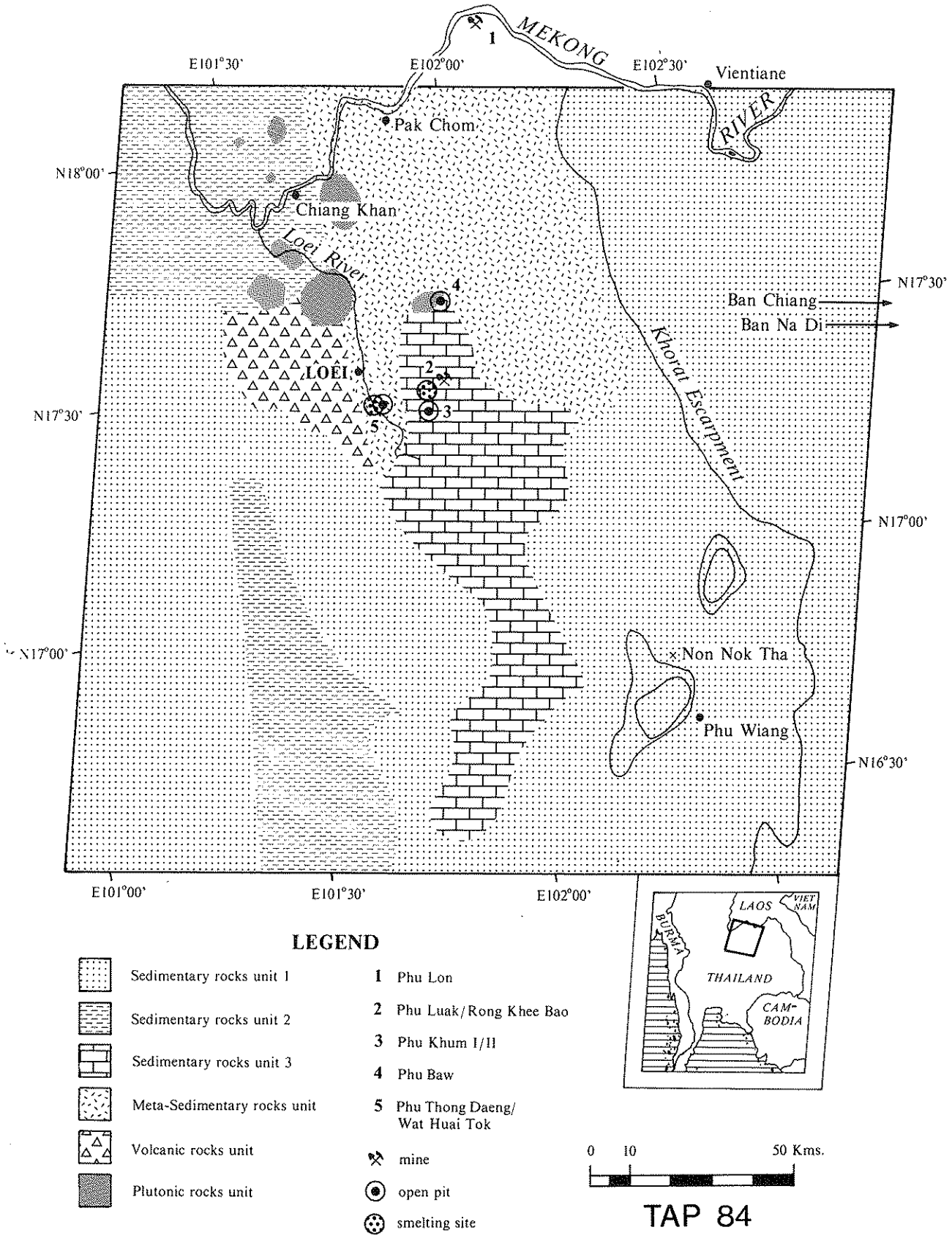
Stage I: TAP84 survey of base metal resources

In January and February 1984 an intensive survey of base metal (copper-lead-zinc) ore sources and their immediate vicinities in Loei province was conducted by the author and two Thai colleagues, Udom Theetiparivatra, a geologist with the Loei office of the Department of Mineral Resources (DMR) and Surapol Natapintu, an archaeologist with the Fine Arts Department. Our intention was to look for pre-industrial exploitation of the deposits, as well as indications of associated metal production. Mining complexes (mining and related activities), open pits, metal production sites, and occupation sites with metalworking debris were all identified during the survey. Of these the mining complexes provided the most significant evidence of pre-industrial activity (see Fig. 1: Sites 1 and 2).

Two major complexes were identified. The first was a copper mining site (Phu Lon) with a pronounced prehistoric component. Upon completion of a test trench at this site during the TAP84 season, it was decided that the team would return in 1985 to undertake more extensive excavation aimed at determining the nature of ancient mineral exploitation. From the test trench a single ^{14}C sample provided a corrected date of *circa* 450-395 B.C. (P-3475)* for an ore crushing activity area known as the Pottery Flat.

The second complex, tentatively dated to the later historic period, *circa* 10th century A.D. and beyond, was devoted to the mining and smelting of lead-zinc ores. Two sites, a lead-zinc mine at Phu Luak, and a large smelting site 1 km away at Rong Khee Bao ("Slag Stream"), constitute this major production complex. The mountain of Phu Luak has a maze-like series of deep shafts and galleries, some galleries several meters high and as much as 15 m wide. Unfortunately, no evidence was found which might facilitate dating the mining activity. Based on the extent of the mine itself, it would appear that mining continued over a long period. The smelting site comprises a large slag field (approximately 500 × 50 m) along the banks of a stream. Recent cultivation is gradually disturbing the mounds of slag and exposing an array of smelting debris such as tuyeres, iron oxides and limestone (fluxes?) and ore fragments of the type found at Phu Luak. Historic period stoneware sherds, as well as

Fig. 1:
Map showing locations of main sites encountered on TAP84 survey. Sites are shown in association with the major lithologic units interpreted from enhanced LANDSAT imagery of Loei province, Northeast Thailand.
(Base map: After Jantaranipa *et al.* 1981, Fig. 27.)


MEKONG
RIVER
1
E101°30'
E102°00'
E102°30'
Vientiane
Pak Chom
N18°00'
Chiang Khan
Loei River
4
N17°30'
Ban Chiang
Ban Na Di
LOEI
2
3
5
Khorat Escarpment
N17°30'
N17°00'
N17°00'
Non Nok Tha
Phu Wiang
N16°30'
E101°00'
E101°30'
E102°00'
LAOS
VIET NAM
BURMA
THAILAND
CAM-BODIA
LEGEND
Sedimentary rocks unit 1
Sedimentary rocks unit 2
Sedimentary rocks unit 3
Meta-Sedimentary rocks unit
Volcanic rocks unit
Plutonic rocks unit
1 Phu Lon
2 Phu Luak/Rong Khee Bao
3 Phu Khum I/II
4 Phu Baw
5 Phu Thong Daeng/ Wat Huai Tok
mine
open pit
smelting site
0 10 50 Kms.

TAP 84

sherds of Chinese export porcelain, attest to a later date for the smelting activity here. Until analytical work is completed on the slag from this site we can only presume that the extraction of lead was the primary objective with zinc or zinc oxide as possible by-products if the requisite technology was available.

The other types of sites surveyed in TAP84 were of lesser significance and are discussed elsewhere (see Pigott 1984; Pigott and Natapintu 1984).

Stage II: TAP85 excavations at Phu Lon

Excavations at Phu Lon were undertaken in several discrete areas of the site by the author and Thai co-researchers Natapintu and Theetiparivatra, joined by geologist William Vernon (MASCA and Dickinson College), and archaeologist Roberto Ciarla (Istituto Italiano per il Medio ed Estremo Oriente, Rome). Mining archaeologist Gerd Weisgerber (Deutsches Bergbau-Museum, Bochum) provided a valuable perspective on the mining activity at Phu Lon. Petar Glumac, graduate student in anthropology (University of California, Berkeley) contributed his expertise to the excavation during a short visit. We were assisted by the Northeast Thailand Archaeology Project (NETAP), a team of FAD archaeologists and support staff based in Kon Kaen and directed by Sathaporn Kwanyuen.

The team's geologists identified the exposed rock at Phu Lon as an extensively weathered skarn deposit composed mainly of the iron oxides (goethite, limonite, hematite, and magnetite) along with many veins and pockets of quartz. Among the associated minerals in these veins are malachite and possibly small quantities of native copper. Very localized traces of galena and sphalerite were also identified. Vernon suggests that the ore deposit at Phu Lon is a typical contact metasomatic deposit consisting of a sulfide ore body with an indigenous oxide zone exposed at the surface. The deposit is probably the result of emanations from a granodiorite intrusion into a limestone formation. Thus the miners working Phu Lon over the centuries were obtaining the easily smelted carbonate ore of copper (malachite) and indications are that they may also have obtained easily melted native copper. It is important to note that neither of these pyrotechnological processes will produce significant amounts of slag. The availability of native copper in the region is of particular interest for it may have been used in the earliest manipulations of metals in the region of Southeast Asia.

The areas excavated at Phu Lon documented the activities of mining and ore processing. The area which most clearly demonstrated prehistoric activities undertaken at the site was the Pottery Flat where, it appears, the mined ores were prepared. This involved the crushing of the ores to extract the rich, green bits of malachite trapped in a skarn/quartz matrix. Apparently this was done with hand-held crushing stones obtained from the nearby Mekong river bed (Plate 1). These crushers were used against flat surfaced anvil stones placed on the ground in front of the person doing the crushing. This activity resulted in the formation of a broad, single stratum (S1)

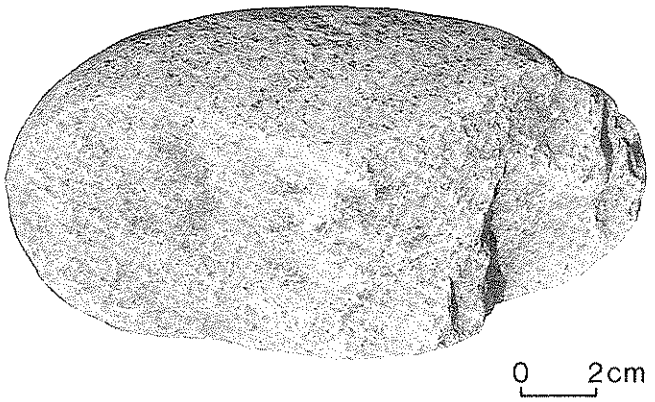


Plate 1:
Broken igneous river-cobble hammer from Phu Lon, typically used in mining and perhaps ore crushing.
(Photograph: Courtesy of U. Theetiparivatra, DMR.)

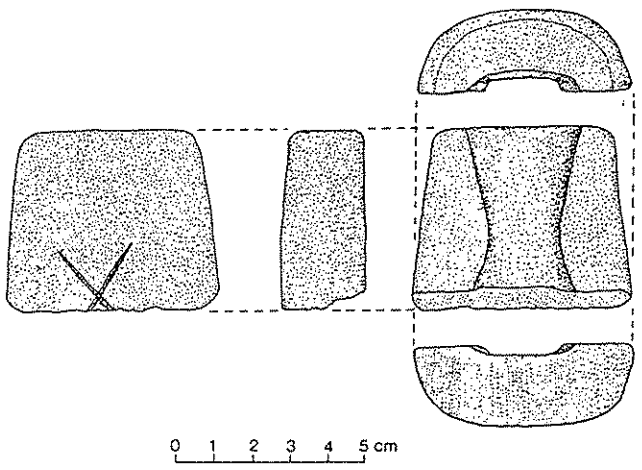


Fig. 2:
Fragmentary half of a bivalve sandstone mold for casting a socketed tool. Obverse side of mold has a large "X" scratched on its surface. This mold fragment was one of two such fragments (the other ceramic) excavated from the crushed ore deposit on the Pottery Flat at Phu Lon. (Drawing by NETAP artist: Courtesy of the National Geographic Society.)

from 15 to 50 cm thick, spread across much of the Pottery Flat. Eight 4 × 4 m excavation squares exposed 200 sq. m of this stratum of crushed ore and artifacts. Test trenches dug across the Pottery Flat showed that the stratum extended well beyond this excavated area.

Among the other cultural materials identified in S1 was an abundance of charcoal, in the large amounts necessary for the melting of native copper and for the reduction of the malachite, an ore rich in copper and low in impurities. Copper ordinarily melts at 1083°C, a temperature not easily obtained without a very consistent natural draft or the use of the bellows. In

addition, some charcoal would have been used for cooking and heating.

Two mold fragments, one sandstone (Fig. 2) and the other ceramic, found at the Pottery Flat, suggest on-site casting. More than 70 small crucible fragments were recovered from S1 and provide strong evidence for the melting process. On the other hand, no substantial amounts of slag or smelting installations were excavated. For the reduction of malachite a simple bowl furnace would suffice, or perhaps the malachite was simply being reduced in crucibles, a process which is possible with an ore of such high purity (see Tylecote 1974). Neither native copper melting nor crucible smelting necessarily produces significant quantities of slag. Thus at Phu Lon it is possible that a crucible smelting operation took place, as indicated by the presence of malachite ore, crucible fragments, and the apparent absence of slag. This possibility is significant in regard to the indications of metal casting and the small amount of slag in metalworking contexts identified in the excavated prehistoric village sites on the Khorat Plateau.

In addition, chipped stone adzes (Fig. 3), ground stone bracelets (Plate 2), and debris of their manufacture were found in and among the detritus of ore processing in S1, showing the co-occurrence of several technological processes in one activity area. A similar juxtaposition of activities was observed by Natapintu at the copper/bronze production sites near Lopburi in Central Thailand which will be the focus of the TAP86 season.

The extent of the S1 deposit at the Pottery Flat and the depth of the mining rubble in the area of the mine shafts suggest that the exploitation of the ore body at Phu Lon continued for a substantial period, perhaps centuries. The analytical program currently underway at MASCA is designed to characterize the nature of technological activities which, over that time, were responsible for the configuration of the mine itself and for the formation of the deposits excavated at this unusual complex.

Stage III: TAP86 prehistoric copper/bronze production in Central Thailand

During archaeological survey conducted by Natapintu in the Khao Wong Pra Chan Valley of Lopburi Province, a cluster of metalworking sites devoted to copper/bronze production was located. These industrial sites will be the focus of TAP Stage III planned for mid-January to mid-March 1986. One of these is a small copper mining gallery at the top of a mountain (Phu Ka) from which may have come the ores being processed at the sites located in the valley below. Another focus of research will be a large processing site devoted to ore dressing, *i.e.*, the preparation of ores for smelting. This work primarily involved the crushing and sorting, by hand, of the mined ores. The matrix of this deposit, meters deep in places, consists of uniformly sized crushed ore mixed with ceramics of the first millennium B.C. The presence of crushed ore gravel suggests that the small, rich bits of ore were sorted by sieving and winnowing. The S1 deposit in the Pottery Flat at Phu Lon is of similar composition. In addition, the two mis-cast socketed

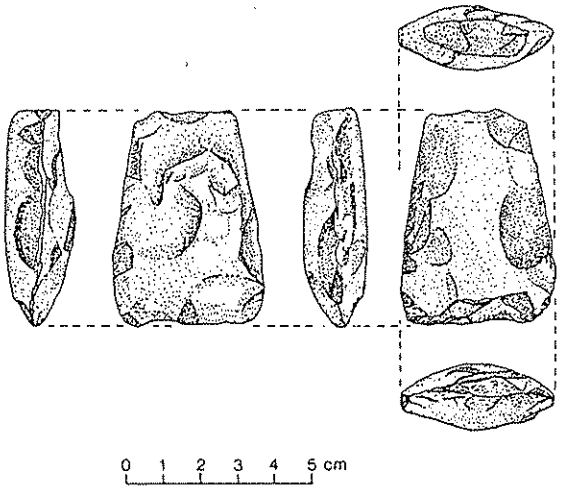


Fig. 3:
Typical example of more than 50 chipped-stone (often shale) adzes excavated from the crushed ore deposit on the Pottery Flat at Phu Lon. (Drawing by NETAP artist: Courtesy of the National Geographic Society.)

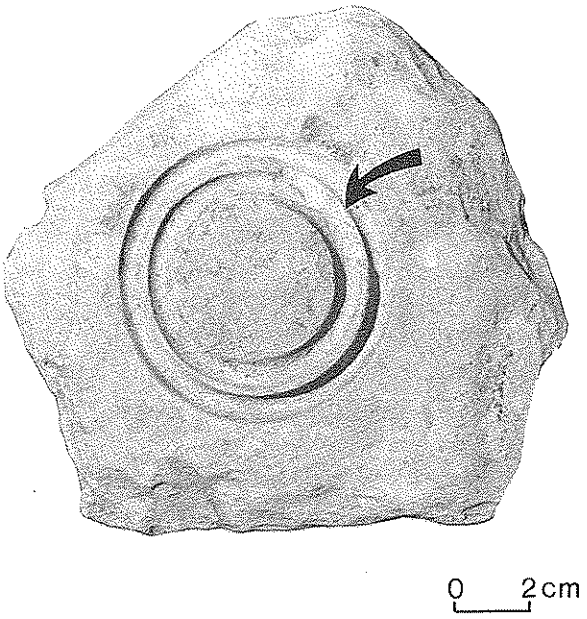


Plate 2:
Dressed shale bracelet "blank" showing concentrically ground rings forming the bracelet between them. Note bracelet body is broken in one portion (see arrow) which may have resulted in the blank having been discarded.
(Photograph: Courtesy of U. Theetiparivatra, DMR.)

copper/bronze axe heads (Plate 3) recovered from the surface of the site suggest that activities other than ore sorting took place there. This impression is reinforced by the recovery of human skeletal remains from beneath the crushed ore in a road cut at one edge of the deposit.

The third site to be investigated is a copper/bronze smelting site consisting basically of thousands of kilos of slag interspersed with abundant charcoal, crushed ore, furnace and crucible fragments, casting molds, and large amounts of animal bone. The bone, which may have been used as a flux in the smelting process, could provide an interesting link between localized animal husbandry and the technology of metal production. In addition, preliminary test trenching at this site by Natapintu revealed cultural stratigraphy containing copper/bronze artifacts, first millennium B.C. ceramics, and meager human skeletal remains. This evidence supports the suggestion that habitation and industrial activities were juxtaposed in the cluster of metalworking sites in the valley.

The investigation of these sites should shed light on the technological processes as seen at Phu Lon, ore dressing for example, as well as on processes not seen there, namely large scale, slag-producing, copper smelting. It will be a matter of some interest to determine whether or not evidence of the production of bronze is present in the context of this cluster of prehistoric industrial sites.

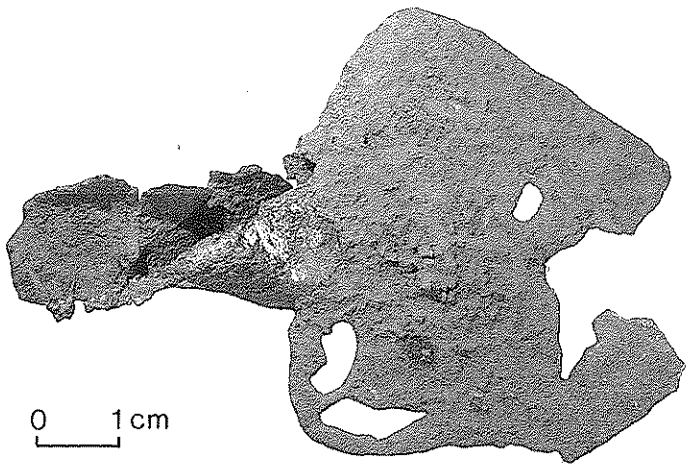


Plate 3:
Mis-cast, copper/bronze socketed axe from surface of ore crushing deposit at site in the Khao Wong Pra Chan Valley.
(Photograph: Courtesy of S. Natapintu, FAD.)

Conclusion

A program of laboratory investigation designed to complement the traditional archaeological assessment of the TAP survey and excavations is being conducted through MASCA and affiliated institutions. Archaeological materials undergoing laboratory analysis include potsherds, crucible, furnace and mold fragments, ore minerals, smelting slag, and metal artifacts. Our expectation is that the results of the laboratory analyses, together with traditional archaeological study of the artifacts, will enable us to reconstruct the technological processes which resulted in the excavated materials. The analyses of these technological products within their particular, archaeologically defined, socio-cultural contexts will facilitate our understanding of prehistoric cultural development and technological change in Thailand/Southeast Asia.

Acknowledgments

The TAP84 survey was made possible through the generosity of The University Museum. TAP85 excavations at Phu Lon were supported by a grant from the National Geographic Society. In addition, the Thai Fine Arts Department and the Department of Mineral Resources have provided invaluable assistance throughout the course of the Thailand Archaeometallurgy Project's existence. TAP staff would also like to thank Joyce White of the Ban Chiang Project for her assistance and interest in our research.

*Regarding the single ^{14}C date from Phu Lon, CRD-1σ refers to dates calibrated with tables that have been produced with 1 sigma uncertainties (Jeffrey Klein, unpublished), but used the same data base and statistical methods as found in Klein *et al.* 1982.

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