Chapter 28
The Transmission of Early Bronze Technology to Thailand: New Perspectives

Joyce C. White and Elizabeth G. Hamilton

Introduction

Archaeological research in Southeast Asia is a relatively new field and there are huge gaps in our fundamental data and understanding. Large areas such as Myanmar and Laos remain little explored. Even in subregions such as Northeast Thailand, where there have been several decades of research, the data are quite thin. For example, there are no fully articulated, dated and published, and stratigraphically based regional ceramic sequences widely used by prehistorians in mainland Southeast Asia. Southeast Asian archaeologists debate many of the most basic aspects of regional culture history—how old a pottery type is; when glass, iron, or any other technology first appears; when and where social forms such as chiefdoms or states first appear; and so forth. The paucity of much basic archaeological evidence does not, however, dampen the interest in broader disciplinary questions such as why and how technological, social, economic, and other changes have occurred, even if the data allow only preliminary and speculative statements rather than enduring and quantitatively based assessments.

When, where, and by what mechanisms bronze metallurgy first appeared in Southeast Asia have been topics of scholarly debate for more than 40 years. Because the evidence for the earliest bronze metallurgy in the region indicates that it appeared fully developed, and no signs of an experimental period have been found, the scholarly consensus, despite occasional flashes of discussion (e.g., Higham 1996, 2002, p. 166, 353, 2006, p. 19; vide Sherratt 2006, pp. 43–44), is that metallurgy—the

---

J. C. White (✉)
Asian Section, University of Pennsylvania Museum,
3260 South Street, Philadelphia, PA 19104, USA
e-mail: banchang@sas.upenn.edu

E. G. Hamilton
University of Pennsylvania Museum, 3260 South Street,
Philadelphia, PA 19104, USA

B. W. Roberts, C. P. Thornton (eds.), *Archaeometallurgy in Global Perspective,*
DOI 10.1007/978-1-4614-9017-3_28,

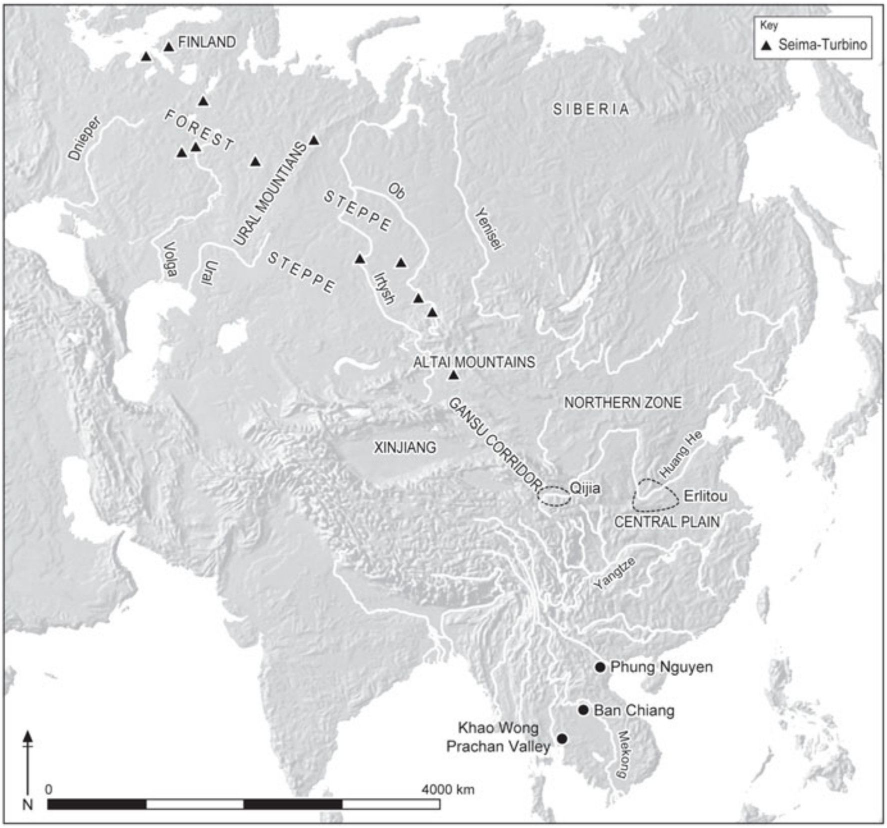

Fig. 28.1 Map of Asia and eastern Europe showing important sites and geographic features mentioned in the text. (Adapted from the Encyclopedic World Atlas 2002, p. 10. Seima–Turbino sites (*triangles*) in Eurasia are taken from Chernykh 1992, p. 192. Ardeth Abrams, illustrator)

system of manufacturing, distributing, and using metals and metal objects—was derived from elsewhere (Roberts et al. 2009, p. 1016). The dating and source of the earliest metals in the region remains a major topic of dispute even today (Higham and Higham 2009; Pigott and Ciarla 2007; White 2008). Scholars interested in the issues include many who are not regional prehistorians (Linduff 1998, p. 633; Mair 1998a; Muhly 1988; Sherratt 2006), because metal technology may be one of the best media through which to explore the details of sociocultural interactions and relations across Eurasia from the fourth through to the first millennium BC (Kohl 2008). In short, understanding the adoption of metallurgy in mainland Southeast Asia could provide important insights into the nature and events of late Holocene Eurasian technology and culture at a continental scale (Sherratt 2006, pp. 43–44).

Most current attempts to explain the appearance of bronze in Southeast Asia look north to early states of the Huang He (Yellow River) Central Plain and their sophisticated bronze tradition for the initial stimulus for bronze metallurgy reaching Southeast Asia (Fig. 28.1; Higham 1996, 2002; Pigott and Ciarla 2007). In this chapter, mainland Southeast Asia refers to the territory encompassed by modern Myanmar (Burma), Thailand, Laos, Vietnam, Cambodia, and the peninsular portion of Malaysia. (To avoid any implied conflation of the modern nation-state of China with past cultures that existed within its territory, we use People's Republic of China or PRC to refer to the modern nation-state, and geographic terms such as river basins or specific provinces when referring to a geographic zone or subunits within PRC boundaries inhabited by past societies).

Proposals for the source of Southeast Asian bronze technology that look to the Huang He Central Plain are framed in a diffusionist idiom (cf. Kroeber 1963 [1923]), e.g., tracing the geography of cultural traits in terms such as the "spread of the idea" of smelting from the more sophisticated Erlitou–Erligang–Shang Chinese cultures to the less-complex societies of Southeast Asia via networks of contact and exchange. We argue that these Sinocentric models are flawed for chronological, technological, and conceptual reasons.

One conceptual problem in Sinocentric models is the primacy given to state-level societies in traditional understandings of the Bronze Age.

> In all other corners of the Bronze Age world—China, Mesopotamia, Anatolia, the Aegean, and central Europe—we find the introduction of bronze metallurgy associated with a complex of social, political, and economic developments that mark the "rise of the state." Only in Southeast Asia, especially in Thailand and Vietnam, do these developments seem to be missing, and explaining (or eliminating) this anomalous situation is one of the major challenges of archaeological and archaeometallurgical research during the next decade. (Muhly 1988, p. 16)

This oft-cited quotation has stimulated considerable research and discussion by Southeast Asian archaeologists in the years since its publication. Some (e.g., Higham 1996, 2006, p. 19, 2009; Higham and Higham 2009) have sought to eliminate the "anomaly" by advocating short chronologies and seeking evidence for a clear relationship between bronze metallurgy in Southeast Asia and intra- and extraregional development of economic and political élites, marked social hierarchies, and state formation activities. Others (O'Reilly 2001; White 1995; White and Pigott 1996) have examined the socioeconomic context for early metal-using cultures in Southeast Asia to understand how nonurban, nonstate societies organized production and use of metals in less-stratified configurations.

Since the discovery of early bronze in Thailand, the opening of formerly inaccessible parts of the Eurasian continent to modern archaeological research, and translations of Russian and Chinese archaeology have provided new data and new conceptual models pertinent to the history of metals in Asia (Linduff and Mei 2009). New evidence ranges from discovery and definition of formerly unknown bronze-producing cultures, such as Tianshanbeilu in eastern Xinjiang (Mei 2003, 2004), to recognition of the great cultural dynamism of metal-using societies in central parts of Asia, beginning in the fourth millennium BC (Anthony 2007; Chernykh 1992; Kohl 2007, 2008; Koryakova and Epimakhov 2007; Kuz'mina 2008; Linduff 2004a; Mair 1998b), to new accelerator mass spectrometry (AMS) dates that have provided an absolute chronology for, and sometimes reordered, cultural sequences that had previously been organized using relative culture-historical frameworks with poor or no chronometric evidence (e.g., Hanks et al. 2007).

As more nonstate bronze-producing societies have been discovered or made better known by the availability of translations of Russian archaeological scholarship, the idea that the Bronze Age was necessarily associated with early state formation (e.g., Muhly 1988, p. 16) has required revision (Linduff and Mei 2009). Examinations of the spread of metallurgy in nonurbanized Eurasia by Chernykh (1992, p. 191) and Kohl (2007, pp. 178–179) led to the observation that "the Late Bronze archaeological record for the western Eurasian steppes documents relations that are more egalitarian and less stratified than what is known of the Early and Middle Bronze periods" (Kohl 2007, pp. 178–179). Kohl's (2007) concluding Chap. 6 portrays a vastly different, richer, and more diverse Bronze Age than the one envisioned in the influential but now dated Muhly quotation. In the context of these nonurban, less-stratified Eurasian Bronze Age societies, the weakly ranked metal-producing prehistoric societies of Thailand appear less aberrant than when they were first discovered.

Recent scholarship on the anthropology of technology transmission (e.g., O'Brien 2008; Schiffer 2001a, b, 2005, 2008) also provides new conceptual tools with which to address the complexities of why and how technologies move from one society to another. In this regard, it is important to differentiate a "technology" (the application of knowledge of the material properties of physical things to achieve practical purposes) from a "technological system" (the way technological knowledge is implemented in a specific context). So for example, during the second millennium BC, the Huang He Central Plain states and Southeast Asia each had knowledge of bronze technology, but the technological systems for producing and using bronze artifacts in the two regions were markedly different.

The production of metal and metal artifacts is a "complex technological system," here defined as a system involving suites of interacting technologies comprising more than one material and requiring multiple production steps (modified from Schiffer 2005; see also Costin 2005, p. 1054). Technological knowledge is applied to the manipulation of two or more materials in order to attain a finished product, and a division of labor is also required to conduct the full sequence of steps to implement the technology. The smelting of copper and the production of bronze artifacts are parts of a complex technological system involving the acquisition and manipulation of ores and fuels, the creation of refractory ceramics, the refining of molten metal, alloying, casting, fabrication, and manipulation of molds, and the management of post-casting treatments such as working. When one appreciates the amount of knowledge, and the number of skills and steps involved in even the simplest metal production system, it is difficult to imagine how the transfer of this technology to a society with no prior experience of working with metals could occur without direct instruction.

As ancient metal production systems around the world are studied, it is clear that different solutions to the innumerable technological challenges entailed in creating metal artifacts have been developed by different societies. These variant solutions have been considered " technological choices," in that other possible roads to addressing that technical problem exist and were in fact likely known. For example, one society chooses blowpipes, another double piston bellows to apply air to raise temperatures during a smelt, and frequently choices are made for reasons unconnected with Western notions of labor efficiency or scale (Epstein 1993; Hosler 1995; Killick

Table 28.1 Lower Early Period metal artifacts and crucibles found at Ban Chiang

BC			BCES		
Levels	Burial metals	Nonburial metals	Levels	Burial metals	Nonburial metals
7		3 amorphous	2d	5 bangles	–
		2 flat	2c	–	1 crucible fragment 1 amorphous
		2 crucible fragments	2b	–	1 wire/rod
6		2 amorphous 1 slag 1 crucible fragment	2a	1 spear point	1 flat
5		1 flat 2 amorphous 1 wire/rod	1a		
4		1 amorphous			
Total		16		10	

BC the 1974 excavation, *BCES* the 1975 excavation, 100 meters from BC

2004; Schiffer 2004). Defining the particular technological system of an area and its range of technological choices requires investigating not only finished products, but also the manufacturing equipment and debris, evidence of the production steps, the materials technology for both finished products and manufacturing equipment, and the systemic interrelationships among all these components. To determine the source of the knowledge of metalworking in Southeast Asia requires looking at not merely who produced the geographically nearest metal artifacts at a suitable period of time, but who produced the nearest artifacts using a similar technological system.

Transmission of complex metal technologies to an area with no prior experience in metalworking is not likely to have occurred by mere exposure to the idea of smelting or by emulation of goods made of metal (vide Schiffer 2008, p. 107; Van Pool 2008), particularly in areas lacking evidence of a period of experimentation. We now review the technological system evident in the earliest bronze evidence of Southeast Asia in order to better assess its possible source(s).

The Early Southeast Asian Metallurgical System

The Earliest Metal Evidence

The clearest evidence for the appearance of metallurgy in Southeast Asia comes from Ban Chiang in Northeast Thailand (Table 28.1), from the excavations conducted by the University of Pennsylvania Museum and the Fine Arts Department of Thailand in 1974 and 1975 (hereafter Penn/FAD excavations). Ban Chiang is a mixed mortuary/occupation site with prehistoric deposits extending at least from the late third millennium BC to the first millennium AD. (All chronometric dates presented here are calibrated, based on the IntCal04 calibration curve by OxCal v. 4.0.1.) The earliest metal evidence comes from the Ban Chiang lower Early Period. AMS dates on rice inclusions in burial pottery provide a range of c. 2100–1700 BC for the lower Early Period of the site (White 2008). Bronze is missing from the very lowest cultural contexts in the lower Early Period, but fragments are found in occupation contexts in levels producing AMS dates around 2000 BC. The earliest metal grave good recovered from the Penn/FAD excavations, a bent-tip socketed spear point (Fig. 28.2a), comes from a lower Early Period level which dates around 1800 BC (a full discussion of AMS dating of early Ban Chiang metals is in White 1997 and 2008).

Of the 26 metal or metal-related artifacts excavated from lower Early Period burial and nonburial contexts at Ban Chiang by Penn/FAD (Table 28.1), five copper-base bangles (Fig. 28.2b) and one copper-base socketed spear point (Fig. 28.2a) were grave goods. One wire, one rod, four flat pieces (possibly fragments from implements), and nine amorphous copper-base pieces (probably casting spillage) came from nonburial occupation contexts such as general soil matrix, features, or fill around graves. The presence of one piece of slag and four crucible fragments from Ban Chiang lower Early Period contexts suggests that on-site casting (but not necessarily smelting) was practiced from the initial appearance of metal at the site. This early second millennium BC evidence supports the conclusion that bronze appeared at Ban Chiang as a fully developed technology.

Evidence from other Southeast Asian sites of copper-base metallurgy older than 1500 BC is rare and less thoroughly documented than at Ban Chiang. The dating of the earliest copper-base metals from the mortuary/occupation site of Non Nok Tha has long been debated (Bayard 1972, 1979, 1981, 1996–1997; Higham 1996–1997, 2002, p. 129, 2004; Solheim 1968); but there is evidence that the oldest metal there, including a remarkable, thin-walled, deep-socketed tin-bronze implement (known by the nickname WOST, for World's Oldest Socketed Tool; Fig. 28.2c), could date to the late third millennium BC (Bacus 2006; Bayard 1996–1997; Higham 1989, p. 98, 102; Spriggs 1996–1997, p. 943). In central Thailand, a bronze bar recovered from a lower Bronze Phase burial 6ii at Ban Mai Chaimongkol (Fig. 28.2d) has been cross-dated to some time during the early second millennium BC, based on its position in the Ban Mai Chaimongkol ceramic sequence relative to dated ceramic sequences from other sites in central Thailand (Onsuwan 2000, p. 114; Eyre 2006, pp. 100–101, 161, 327). In northern Vietnam, the earliest appearance of copper-base artifacts appears to date from the early second millennium BC in deposits from Phung Nguyen and other contemporaneous cultures. The earliest metal remains are described as "bronze waste material" from six Phung Nguyen sites, "traces of bronze" from Doan Thuong, a site related to Ma Dong, and "two baked clay casting moulds" from the late Phung Nguyen site of Dong Vong (Huyen 2004, p. 190).

In summary, the earliest evidence for copper-base technology in Southeast Asia consists of: (1) jewelry, particularly bangles; (2) socketed implements, cast in bivalve molds with suspended cores (the Ban Chiang bent-tip spear point and the Non

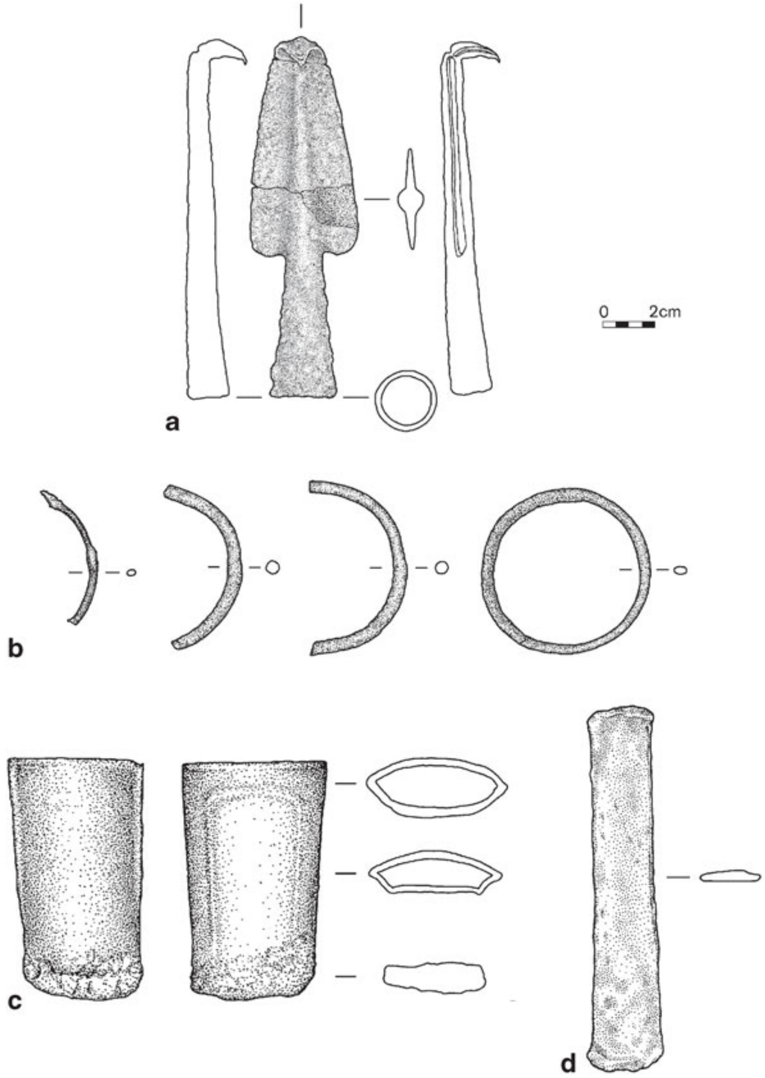

Fig. 28.2 Bronze grave goods from prehistoric Thailand, from the early second millennium BC. **a** Socketed bent-tip spear point BCES 762/2834, from Ban Chiang BCES Burial 76, the flexed grave of a 25–30-year-old man. **b** Anklets BCES 526/1592, BCES 594/1984, BCES 595/1984, and BCES 596A/1984, from Ban Chiang BCES Burial 38, a supine burial of a child about 4 years old. **c** Deep-socketed implement NNT-152, from Non Nok Tha. **d** Bar from Ban Mai Chaimongkol Burial 6ii

Nok Tha deep-socketed implement); (3) flat cast artifacts, including the Ban Mai Chaimongkol bar and occasional fishhooks and arrowheads; (4) flat and rod-like pieces that could have been fragments of implements; (5) small amorphous pieces, most of which are probably casting spillage; (6) crucibles and crucible fragments; and (7) ceramic casting molds.

Technological System Overview: Evidence for Style and Choices

Raw Material Acquisition

Elemental analyses of prehistoric copper-base artifacts from Thailand indicate that tin bronze was the preferred metal from the initial appearance of copper-base metallurgy, so the earliest metalworkers needed to obtain both tin and copper. Systematic archaeological research into how copper was obtained in prehistory has only just begun. The Thailand Archaeometallurgy Project (Pigott 1998; Pigott and Natapintu 1988; Pigott and Weisgerber 1998; Pigott et al. 1997) has documented two major locations with evidence of prehistoric copper production. Phu Lon in Northeast Thailand is a copper mining complex located along the Mekong River about 160 kilometers west of Ban Chiang. The Khao Wong Prachan valley in central Thailand has at least three substantial outcrops of copper ore and several ore-processing/smelting sites in their vicinity. No evidence for mining or smelting that dates to the early second millennium BC has been excavated in Southeast Asia, but evidence from these two localities exploited some centuries later can be used to gain some understanding of probable early procedures.

Phu Lon, where the principal ore mined was malachite, has at least two well-defined locales for ore processing located in the immediate vicinity of the mining areas. The early mining efforts consisted of grubbing surface exposures with heavy oblong river cobbles, resulting in small, rounded pits (Pigott and Natapintu 1996–1997, pp. 789–790). These hammerstones may have been handheld, as there is no hafting groove or other indication of hafting (Pigott and Weisgerber 1998). During later periods of use, mine shafts following mineral veins were created. Eventually, it appears, the profusion of mine shafts and galleries in the hill led to the mine collapsing in on itself (Pigott and Weisgerber 1998). Hundreds of stone-mining mauls and ore-crushing tools were found around the site, with the latter especially in ore-crushing locations. Some 96 fragments of crucibles were recovered, often with some adhering slag, of the same morphology but perhaps somewhat smaller than the crucibles found at Ban Chiang and related sites (Vernon 1996–1997). In the absence of fixed installations such as bowl furnaces, it has been suggested that these crucibles were used in smelting processes (Pigott and Natapintu 1996–1997, p. 793). In the slag adhering to crucibles were found prills of copper, tin, and tin bronze, showing that these metals were processed in the crucibles at Phu Lon as well (Pigott 1998; Pigott and Natapintu 1988; Pigott and Weisgerber 1998; Vernon 1996–1997). Tin ore such as cassiterite is not known to exist in the immediate vicinity of Phu Lon; thus, it is possible that tin smelted from elsewhere, or cassiterite itself, was brought to Phu Lon for processing. Sources of alluvial tin are known in northern Laos across the Mekong. Most of the Phu Lon mining and ore-processing remains date from the first millennium BC. There is one mid-second millennium BC date which could suggest earlier activity at the mine. Mining at Phu Lon appears to have been small scale, episodic, and probably seasonal, though exploitation did continue for centuries.

In contrast to the relatively small-scale metal exploitation at Phu Lon, the Khao Wong Prachan valley in central Thailand has evidence for more ore resource locales and more intensive use (Natapintu 1988). Two copper-production sites in the Khao Wong Prachan valley, Non Pa Wai and Nil Kham Haeng, are among the largest prehistoric copper production sites currently known in Asia. The slag remains at Non Pa Wai alone are estimated to weigh hundreds of thousands of tons (Pigott 1999). Unlike at Phu Lon, where the ore-processing locations were adjacent to the mine, the Khao Wong Prachan ore-processing/smelting localities are a couple of kilometers from the probable locations of the actual copper mines. The metal-processing sites suggest sustained prehistoric use, which the excavators argue began sometime after 1500 BC and continued through the first millennium BC (Pigott 1999). Non Pa Wai has evidence of use as a smelting location with its meters-thick deposit of slag, ore, crucible fragments, and cup/conical molds probably used for ingot production. At the base of the deposit are human burials, some of which are thought to date from the late third or early second millennium BC. The earliest burials are not considered related to metallurgical activity, but later burials probably dating to the later second millennium BC contained ceramic bivalve mold pairs for the casting of deep-socketed adze–axes. Massive ore crushing and copper smelting took place at Nil Kham Haeng during the first millennium BC and, as a site, its matrix is composed primarily of slag and crushed ore/host rock. The site yielded mortuary remains from throughout its sequence. Unlike Phu Lon, no evidence of alloying or tin processing has yet been found at Khao Wong Prachan sites.

The ore deposits in the Khao Wong Prachan valley are rich in both iron and copper; the copper deposits include malachite, chrysocolla, and chalcopyrite (Natapintu 1988). Analysis of the ore fragments found in the cultural deposits shows that both oxidic and sulfidic copper ores were smelted (Pryce and Pigott 2008). Rostoker et al. (1989) suggested that the copper metal was produced by co-smelting, involving the inadvertent and simultaneous reduction of oxidic and sulfidic ores. Co-smelting produces metal in a direct one-step process, which may yield large quantities of slag (Pigott 1999; Rostoker et al. 1989). In co-smelting, along with smelted copper, some residual matte is often produced which could then be resmelted to copper. Successful co-smelting requires only a high temperature ($\sim 1250\,^{\circ}\mathrm{C}$) and a sulfur-rich atmosphere (Rostoker et al. 1989), but no fixed installations, and can be driven by dry wood fuel. Slag cakes, often fragmentary, were recovered from Non Pa Wai, probably resulting from the pouring out of the smelt product from crucibles on to the ground. At Nil Kham Haeng somewhat different procedures were used and the slag, on current evidence, is presumed to have formed in shallow bowl furnaces lined with chaff-tempered clay. Following smelting the slag was systematically crushed and could have been used for fluxing and resmelting. At Nil Kham Haeng, it is possible that lower-grade ores with higher sulfide contents were increasingly employed as higher-grade oxidic deposits were depleted by intensive production in the region (Pigott 1998; Pryce 2009; Pryce and Pigott 2008).

More investigation of these and other mining and ore-processing sites in Southeast Asia is needed, but one can make some observations regarding technological choices in the early evidence for ore acquisition at these sites. Although the Khao

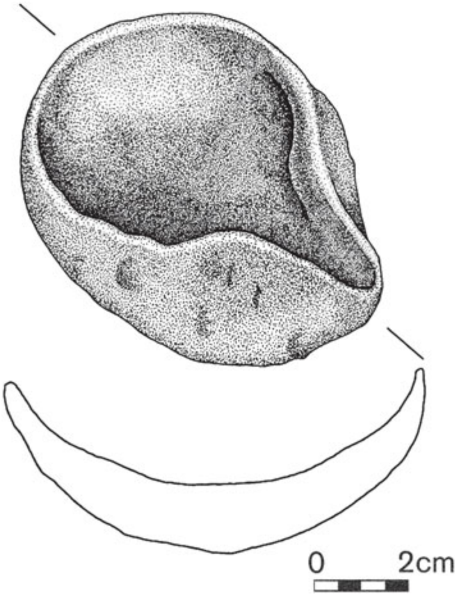

Fig. 28.3 An intact crucible from Ban Chiang illustrating the common Southeast Asian internally heated crucible type

Wong Prachan valley sites, based on the enormous volumes of production debris, strongly suggest greater intensity of exploitation than Phu Lon, with more output and greater permanency of residence, the two areas have elements in common. In both areas, evaluation of the evidence for production organization, in light of Costin's (1991) criteria, strongly suggests that small, essentially autonomous work units of labor, such as households, undertook metal processing using flexible low-technology approaches (White and Pigott 1996).

Refractories

The refractory technological systems in prehistoric Thailand suggest a preference for flexible, portable, multiuse equipment over specialized, task-specific, or large-volume equipment. The evidence indicates that both smelting and melting of metal were done in portable, internally heated crucibles, at least initially, with the later addition of the bowl furnaces at Nil Kham Haeng that date to the first millennium BC.

Common Southeast Asian Crucible Production

The earliest, simplest, and apparently most widespread crucibles are small, usually spouted bowls (Fig. 28.3). Such crucibles (which, because of their wide distribution, we will call "common Southeast Asian crucibles") are found at many mortuary/occupation sites in Northeast Thailand, including Ban Chiang, Ban Tong, Ban Phak Top, and Don Klang (Vernon 1996–1997, 1997), Ban Na Di (Higham and Kijngam 1984, p. 130), Non Nok Tha (Bayard and Solheim 1991), and Ban Non Wat (Higham 2008), as well as at the mining site of Phu Lon (Vernon 1996–1997). Natapintu (1988, p. 122) illustrates an example from Noen Klong Bamrung in central Thailand. Higham (1984, p. 236) implies that similar crucibles are also found in North to South Vietnam and central Cambodia. Spouted crucibles have been noted in Cambodia at Samrong Sen (date unknown), and a larger one (16 cm high) in Dongson contexts at Lang Ca (Murowchick 1988, p. 190, Fig. 17.18). The evidence from Northeast Thailand suggests that these small crucibles were used for all processes requiring containment of molten metal, including smelting, refining, alloying, and melting.

Four fragments of this kind of common crucible, including one fragment with a spout, were found in lower Early Period deposits in Ban Chiang, indicating that this piece of production equipment was adopted at the first appearance of copper-base metallurgy in Thailand. Crucibles of this kind were probably embedded in depressions in the ground or in small hearth-like installations, such as those uncovered at Ban Na Di (Higham 1988, p. 133, Fig. 13.5). The heat source was piled above the crucible and its charge, a point supported by vitrification on the interior of the crucibles (Vernon 1996–1997, p. 816; see also Barnard 1980, pp. 225–227 and Rehren 2003 for descriptions of procedures for using small internally heated crucibles).

Observations made on the Ban Chiang crucibles indicate that their size was suitable for casting the range of copper-base artifacts recovered from the site. This evidence suggests that the goal was to prepare small batches of molten metal suitable for creating one or two artifacts at a time. The crucible fabric is often tempered with rice chaff, which can help the internally heated crucible remain intact during the relatively short processing period necessary for small batches of metal. In the Ban Chiang region, the same crucible type was used for more than two millennia, implying that this refractory style was very successful in meeting the needs of the region's prehistoric societies.

A notable performance-enhancing characteristic of many of the small spouted crucibles is the presence of lagging—a quartz-rich clay slurry lining that probably insulated the earthenware crucibles from the high interior temperatures, helping to prevent cracking of the clay bodies while they held molten metal (Vernon 1997). Lagging may also have facilitated successful pouring of the molten metal during the casting process by preventing the metal from seeping into the crucible body. Lagging contributed to the success of internally heated crucibles made of local earthenware clays that are less refractory than, for example, kaolinite clays.

Technical analysis of the four crucible fragments from lower Early Period Ban Chiang showed that all four had rice husk temper and adhering dross or slag, two had interior vitrification, and a metal prill was extracted from one crucible piece. One with a spout had lagging.

First identified at the mining site of Phu Lon by William Vernon (1996–1997), lagging has since been found in crucibles from most sites in Northeast Thailand where this feature was looked for by analysts (Vernon 1988, 1996–1997; White et al. 1991; Hayden Cawte, personal communication). At least one layer of lagging was present on 62 of the 87 crucibles or crucible fragments found at Ban Chiang, and 31 of the 96 crucible pieces from Phu Lon (Vernon 1996–1997, p. 210). White and Pigott (1996) argued that the finds of the same basic crucible technology near mines, and also in villages some distance from mines, suggest that while primary metal production took place near ore sources, refining and casting took place in the villages. The recovery of these crucibles in the lower Early Period at Ban Chiang, far from ore sources and with almost no evidence for on-site smelting, suggests that a segmented production system (different production steps occurring at different locations) was in place from the initial appearance of metallurgy in Northeast Thailand. More published data on crucibles from other sites in Asia are needed to further define the geographic and temporal extent of common Southeast Asian crucible production.

Khao Wong Prachan Valley Crucible Production

A later crucible variant is found only in central Thailand in the Khao Wong Prachan valley and at a related locus, Khao Sai On about 20 km to the south (Ciarla 1992, p. 126). These distinctive crucibles are unspouted, unlagged (Vincent Pigott, personal communication), and, though the size and shape can be variable, are on average larger ($\sim$ 8–10 cm internal diameter and $\sim$ 12 cm high: Bennett 1988) than the spouted crucibles found in the Northeast, though still portable and internally heated. They were associated with the use of another distinctive piece of refractory equipment—portable reusable furnace chimneys pierced with holes. It is assumed that the holes were for wind or bellows although no traces of tuyères have been found. Pigott suggested that the strong and consistent winds found during the dry season were enough to power small smelts, and this suggestion is being tested experimentally (Pryce 2009; cf. Bunk et al. 2004; Pryce et al. 2007). While distribution of chimneys in the Khao Wong Prachan valley is currently under review, they are particularly common during the first millennium BC at Nil Kham Haeng where they are even found in burials.

Judging from the hundreds of thousands of tons of slag and hundreds of thousands of crucible fragments, industrial-scale production was undertaken at Non Pa Wai and Nil Kham Haeng and probably other nearby localities. Khao Wong Prachan valley crucible production appears to be associated with casting of ingots in cup/conical molds. Small copper artifacts as well as numerous small bivalve molds for casting these small artifacts have also been recovered. Nil Kham Haeng had abundant thin-socketed cordiform-shaped implements (Pigott 1999, p. 18, Fig. 14) of unknown function, along with bivalve molds for casting such objects. The overall evidence is consistent with a step toward mass production, with the larger (but still portable and internally heated) crucibles having a sufficient quantity of molten metal to pour into multiple molds (Pigott 1999; Pigott et al. 1997). During the first millennium BC, small bowl furnaces came into use at Nil Kham Haeng (Pigott et al. 1997).

The relationship (if any) of the Khao Wong Prachan valley crucible production to the common Southeast Asian crucible production is unclear. Although the Khao Wong Prachan valley was occupied prior to 1500 BC (Pigott and Natapintu 1996–1997), no evidence demonstrates that metal was used or produced during the earlier occupation. Nor has the common Southeast Asian crucible type been identified in the valley, although complete bivalve mold pairs for larger socketed adze–axes comparable to those found elsewhere in Southeast Asia have been recovered from later second millennium metalworkers' burials in basal Non Pa Wai (Pigott and Natapintu 1996–1997, p. 798). Nevertheless, despite their differences, both the common and Khao Wong Prachan valley crucible production styles are based on portable, internally heated crucible technology. The Khao Wong Prachan valley was apparently oriented toward higher volume output, larger batch sizes, and more nucleated production, with multiple production steps occurring in close proximity, but still with a mostly portable technology. The enormous number of ingot molds demonstrates that the area was engaged in providing raw material for casting on-site, and probably at other locations.

Alloying

The elemental analyses done thus far indicate that binary tin bronze was the alloy of choice, beginning with the earliest appearance of Southeast Asian prehistoric copper-base artifacts. So far no evidence of working native copper has been found in prehistoric contexts in Thailand (further supporting the lack of an experimental stage in metalworking in the region). Elemental analyses of three lower Early Period artifacts from Ban Chiang graves show that all were 10 % tin bronze, with no other major elements or impurities. The early thin-walled, socketed Non Nok Tha adze is also a binary tin bronze (Selimkhanov 1979). Scanning electron microscopy/Energy dispersive spectrometry (SEM/EDS) analysis of the flat cast bar from Ban Mai Chaimongkol showed that the tin content ranged from 7 to 13 %, with low levels of lead (Nash n. d.). Deliberately shaped, unalloyed copper artifacts are occasionally found at Ban Chiang. Elevated levels of lead, arsenic, and antimony also are sometimes found, but only the lead is thought to have been deliberately added, suggesting that some flexibility in alloying was present in the second millennium BC. The products of the Khao Wong Prachan valley sites were apparently almost entirely unalloyed copper, which suggests that alloying may have varied by production centers. In this regard, it is noteworthy that there are no tin sources close to the Khao Wong Prachan valley. Based on the study of prills in crucibles from Phu Lon (Vernon 1996–1997), we know that some alloying occurred at this primary production site, but based on studies of prills in Ban Chiang crucibles (Vernon, personal communication), alloying was probably also done far from ore sources, at villages which were doing their own artifact casting.

Object Fabrication

Another fundamental component of any metal technological system is how the smelted and alloyed metal was shaped into the desired form of the final product. The discussion below reviews what are believed to be the two most common object fabrication techniques found in prehistoric Thailand (the source of most of the available analytical data): lost wax casting and bivalve mold casting. In prehistoric Thailand, it appears that both formation techniques aimed to cast the object as close as possible to its final shape, with minimal post-casting modifications. Forging (shaping metal by cycles of heating and hammering) and cold working, while occasionally practiced, were overall less important than in western Old World traditions (Sherratt 2006, p. 44). Metallographic analyses of seven Ban Chiang lower Early Period artifacts demonstrated that all but one were left as cast. The bent-tip spear point had been annealed after casting, perhaps to bend the tip, with some possible work before and after annealing (Ban Chiang Project n.d.; Stech and Maddin 1988). A socketed adze–axe from Non Nok Tha was splayed by hammering and annealing (Smith 1973). The flat bar from Ban Mai Chaimongkol was left as cast (Nash n.d.).

Lost Wax Casting

It has long been thought that the main technique used to create bangles, the most common deliberately shaped copper-base artifacts recovered from prehistoric contexts in Thailand, was the lost wax technique (Higham and Kijngam 1984, p. 81, 125; Smith 1973, p. 29; Stech Wheeler and Maddin 1976, p. 43). The earliest bangles are generally simple closed rings whose shafts have a circular cross section; metallography shows bangles are almost always left “as cast.” Fragments identified by the excavators as being from clay lost wax molds for bangles have occasionally been recovered (Higham and Kijngam 1984, p. 128). No univalve or bivalve molds that could create the common simple ring bangles or the more elaborately shaped bangles of later periods have been recovered from Ban Chiang area sites. However, to the south, Higham and Higham (2009, p. 136) report that ceramic bivalve molds for bangles dating to the first millennium BC have been recovered in the upper Mun valley. Over the course of the metal age, 2000 BC – AD 500, more elaborate bangles were made, with complex cross sections, closures, and ornamentation, suggesting that the lost wax technique was gradually exploited for its potential to create complex shapes.

Bivalve Molds with Suspended Cores

A special variant of bivalve mold casting to fabricate socketed implements involves the use of a core or mold plug suspended in the middle of the mold to form a blind (open only at one end) socket in one step with the casting of the working implement. This suspended-core casting of socketed implements was practiced by the early second millennium BC, as evidenced by the bent-tip spear point (Fig. 28.2a), excavated from a Ban Chiang lower Early Period burial. This inference is based on the morphology and metallographic study of the object, as well as the fact that, although no mold pair was found in the lower Early Period at Ban Chiang, stone and ceramic mold halves and full mold pairs for socketed implements, including spear points, have been recovered from other prehistoric metal age sites in Thailand (Non

Nok Tha: Bayard 1980; Non Pa Wai: Pigott 1999; Ban Non Wat: Higham 2008; Cambodia and Vietnam: Murowchick 1988).

The technique of single-process casting of deep blind sockets using bivalve molds with suspended cores is a signature characteristic of the prehistoric Southeast Asian metallurgical tradition. The sockets usually extend deep into the implement, resulting in thin-walled, hollow-core tools, such as the early WOST adze–axe from Non Nok Tha (Fig. 28.2c). Unfortunately, the Ban Chiang spear point (Fig. 28.2a) and Non Nok Tha socketed implement (Fig. 28.2c) were returned to Thailand before their drawings were completed; the depths of the sockets are not indicated. However, see Murowchick (1988, p. 191, Figs. 17.19 and 17.20) for illustrations of similar implements showing the deep sockets of these types of tools.

The formation of the cast blind sockets in bronze implements has been noted as a point of considerable technological significance (Childe 1954; Koryakova and Epimakhov 2007, p. 39; Sherratt 2006, p. 48). More than half a century ago, V. Gordon Childe (1954, p. 11) observed that the technique, which is known by a variety of names including hollow-core casting and core casting, allowed the creation of thin-walled, lightweight tools, reducing the amount of metal needed to create an effective socketed implement. Casting this type of socket is considered more sophisticated than forging the socket around a form as was done in many early metalworking cultures in western Eurasia (for example, at Sintashta: Anthony 2007, p. 444; Sherratt 2006; vide Childe 1954), or casting open-socket forms such as shaft-hole axes, or implements with oblique open sockets such as those identified in the Andronovo technological system (Mei 2000, p. 27, 95, 96).

Casting Small Implements and Other Processes

How other prehistoric copper-base implements, such as the Ban Mai Chaimongkol bar (Fig. 28.2d) and various points, fishhooks, and blades, were formed has not received much attention. Metallographic studies again show that most were cast to shape. A few univalve molds recovered from prehistoric contexts appear to have been used to cast small tanged arrowheads and rings. Bivalve molds can be used to cast tanged implements, although matched mold pairs with tanged point impressions have not as yet been reported in the vicinity of Ban Chiang.

The Organization of Production

White and Pigott (1996) reviewed the archaeological evidence for the organization of production for copper-base metallurgy in prehistoric Thailand in light of Costin's (1991) criteria for different modes of specialized production. The evidence is consistent with production organized into small decentralized production units, possibly kin-based (that is, household production), often in communities, undertaking metal and artifact production in small batches during the dry season. The wide distribution of crucibles in village sites in Northeast Thailand suggests that knowledge, at least of casting, was not restricted in space or by social group, although it is possible that itinerant metalworkers who made crucibles from local clays could also have created such a distribution of crucibles. The regional distribution of crucibles and molds shows that production was segmented geographically, with primary production (mining and smelting) taking place near ore sources and secondary production (such as casting) near consumers. For at least the first thousand years after their first appearance in prehistoric Thailand, metal artifacts have a patchy distribution; a few sites, such as Non Nok Tha, are relatively rich in bronze artifacts, but other contemporaneous sites, such as Ban Lum Khao (Chang 2004, p. 230) and Khok Phanom Di (Higham 1996–1997), have few or none. The early metal and metal artifact production was undertaken at small, apparently autonomous, villages (re Higham 1996, p. 242, 315), with no evidence of centralized control (Pigott 1998), and the products possibly exchanged in the vicinity of each village. The absence of evidence for metalworking in contemporaneous sites in some parts of Thailand (for example, Khok Phanom Di and Khok Charoen) suggests some villages were part of a circuit of production and some were not. There was probably exchange of copper over distances of a few hundred kilometers, as sites like Ban Chiang, where casting was done, are far from ore sources (Pigott 1998). Even the large-scale Khao Wong Prachan valley production appears likely (given the challenges of mining and casting in the wet season) to be a seasonal community specialization, where numerous households undertook production of similar products without coercion or administration by a centralized political authority or economic élite (Pigott 1999). Some villages may have specialized in particular products if they were near a certain raw material; for example, the site of Non Nok Tha, where many adze molds have been discovered, is located near a good source of sandstone for the molds (White and Pigott 1996).

The finished metal artifacts produced during the first two millennia of knowledge of copper-base metallurgy in prehistoric Southeast Asia show a remarkable consistency in artifact repertoire, typological range, and technological style. This enduring coherency led White to propose the existence of a Southeast Asian metallurgical province (White 1982, p. 48; 1988; see also Pigott 1999).

Bronze Consumption

Who were the users of the early bronzes in Southeast Asia, and what roles did metal play in their lives? There is no evidence that this material was of central significance to the everyday utilitarian needs of prehistoric societies in Southeast Asia for the first several centuries of its presence. It was very rare in the first few hundred years, although it did appear in both mortuary and occupation contexts. Nevertheless, there was sufficient demand that quality bronze artifacts were produced, even if not at high volume, for some centuries before the material became more abundant.

Most of the artifacts are small personal ornaments. Based on their occasional occurrence in graves, the bronzes likely had some value as part of mortuary ritual; certainly, the most intact examples were bronzes included in burials as grave goods. Some of the graves richest in ornaments are those of young children. But the rarity in graves does not imply the material itself was extremely precious. For example, 90 % of metal finds at Ban Chiang were not grave goods. Probable casting spillage was a common find, suggesting that spilled metal was not meticulously retrieved for reuse in additional castings. Many of the nonburial metal finds were fragmentary artifacts, suggestive of use in daily life. The implements—points, knives, and fishhooks—were undoubtedly useful, but are not found in quantities or forms that imply that they were essential. There is nothing that is unambiguously a weapon or produced in quantities suggestive of a need for military armaments. Even the spear points, which are rare, could have been used for hunting or even ritual activities like sacrifices. There are no signs of armor, swords, fortifications, or even, among the Ban Chiang and other Bronze Age skeletal populations, traumatic injuries characteristic of endemic warfare (Pietrusewsky and Douglas 2002, p. 117). The most convincing evidence so far recovered by archaeologists in prehistoric Thailand that metal was being turned toward creation of weaponry appears in the late Iron Age, when the quantity of points jumped during the final mortuary phase c. AD 400 at Noen U-Loke (Higham 2007, p. 606). In prehistoric Vietnam, bronze was used more for implements than in prehistoric Thailand, but it was not until the Dongson period of the second half of the first millennium BC that weapons formed a significant percentage of metal artifacts (Murowchick 1988, p. 184).

Most of the sites with metal artifacts also have evidence for metal artifact production in the form of crucible fragments, casting spillage, and/or molds. There is no evidence, however, that the sites that are relatively rich in metal were economically or politically dominant in a region, or exerted any power over other villages. Certain families or small groups within particular villages obtained the metal and made ornaments and small tools, probably for distribution both to other families within the village and to other villages. Yet, extrapolating from mortuary evidence, possession of metal objects does not necessarily indicate great wealth or high hierarchical status; some graves with metal are very poor in other artifact classes and some graves rich in other goods have no metal. More children than adults are found with bronze bangles at Ban Chiang. Nor are there any large, elaborate artifacts designed to display the wealth or status of an entire group, or to be used in group rituals, such as the complex, piece-mold cast Shang ritual vessels or the Dongson bronze drums of the later first millennium BC in Vietnam. The techniques employed are all simple enough to have required no complex hierarchical labor organization or fixed and expensive structures (White and Pigott 1996).

A possible exception to this lack of association between hierarchical status and bronze metal occurs at Ban Non Wat near Phimai in Northeast Thailand, where during its second phase of Bronze Age interments, dated 1000–900 BC, bronzes were found in richly endowed graves (Higham 2009; Higham and Higham 2009, p. 131; Higham and Thosarat 2006). This recent evidence, however, supports the larger regional theme that expressions of social differentiation and the social use and consumption of bronze varied site by site, shifting over time and space (White 1995). Was early bronze—neither used for warfare nor used for a highly regulated prestige good—simply one of a variety of "valuables" that circulated among societies for the conduct and marking of reciprocal social, symbolic, and political transactions, one of many commodities in a regional gift-exchange economy that helped to maintain regional networks of social relationships and alliances (cf. Dalton 1977; Higham 1984)?

Further analysis of the sociopolitical role of metallurgy during its early use on mainland Southeast Asia is beyond the scope of this chapter. Whatever role it played was important enough for groups to go through the trouble of obtaining raw metal, perhaps by traveling to mining sites like Phu Lon to extract and smelt ore, make specialized crucibles using a distinctive technology, and melt, refine, and cast artifacts for daily as well as mortuary use.

In summary, the small, internally heated crucibles made with local clay are a low technology, small scale, and of spatially flexible refractory design that did not require fixed furnace installations or large teams of workers. This spatially flexible technological style facilitated decentralized and segmented production of a limited repertoire of small artifacts, including implements and personal jewelry. Different production steps could be undertaken at primary and secondary metal-processing sites, including average villages far from ore sources, using very similar equipment, without the need for permanent installations. Some processing, such as smelting (primary production), likely took place close to ore sources, and casting (secondary processing) took place at villages at some distance from the primary production sites, but the segmented system was probably flexible and not prescribed. The portable, multipurpose design was also suitable for small production teams and small batch processing requiring short processing times, which implies that efficiency of time and flexibility of location were prized over volume of product. Bronze was used for personal ornaments and implements, and, while not common, bronze artifacts were not the exclusive domain of an élite, but had roles in both daily and mortuary contexts.

Alternative Views of Adoption Processes for Earliest Metallurgy in Southeast Asia

Sinocentric Views of Southeast Asian Bronze Adoption

Since the 1990s, the dominant model has pointed to dynastic China as the source for the bronze technology of Southeast Asia, with knowledge of the technology being transmitted through the mechanism of trade and exchange. The fullest exposition of a Sinocentric view is Charles Higham's *The Bronze Age of Southeast Asia*, published in 1996. Higham's book outlines evidence for a chain of exchange relationships initiated by states in the Huang He Central Plain that led to interactions with Yangtze watershed cultures, who then interacted with societies in the Xijiang watershed of southern China (Lingnan), who ultimately brought metallurgy to mainland Southeast Asia, beginning with northern Vietnam and followed by the Mekong and Chao Phraya drainage basins. Other statements of Sinocentric views also posit the transmission of metals technology from Huang He states to prehistoric Thailand through a similar series of regional steps, cultural filters, and local adaptations (Ciarla 2007; Higham 2006, p. 19; Higham and Thosarat 1998, p. 127; Pigott and Ciarla 2007).

Since Higham's 1996 book, statements on the source for Southeast Asian bronze technology have noted that Huang He Central Plain metallurgy may have had a prior source in the Eurasian steppes, perhaps via Xinjiang, where western and eastern cultures and peoples are now known to have interacted since at least the late third millennium. The technology possibly passed through the Gansu corridor via the Qijia and Siba cultures to the Huang He Central Plain (see Fig. 28.1; An 1993, 1998, 2000; Mei 2000, 2003, 2004; Ciarla 2007, p. 2; Linduff 2000; e.g., Higham 2002, pp. 113–115; Pigott and Ciarla 2007). Nonetheless, Sinocentric models still trace early Southeast Asian metallurgy, via Lingnan and the Yangtze valley, to the spectacular and sophisticated metalworking of Erlitou–Erligang cultures of the Huang He Central Plain. These recent statements argue that the élite desire for goods and raw materials in the early Huang He Central Plain states fueled an ever-expanding regional interaction network that eventually brought the knowledge of bronze working to Southeast Asia.

> Looking at the general picture of the artefact inventories which typify the three main cultural periods of the Central Plain Bronze Age, that is Erlitou (1900–1600 BC), Shang–Erligang (1600–1300 BC) and Shang–Yin (1300–1045 BC). . . we can clearly discern exchange networks which brought highly desired raw materials and goods to the Shang élite centres: jade, turquoise and other semi-precious stones, cowries, turtle carapaces, copper and tin, "slaves", and gold. . . The search for and exchange of these goods and raw materials, implying direct and indirect contacts with quite distant sources, activated an ever increasing and complex chain of interlocked regional interaction spheres. . . through which copper/bronze casting technology eventually reached Southeast Asia. (Pigott and Ciarla 2007, pp. 77–78, emphasis added)

How then are the marked differences in technological system and artifact repertoire of Huang He Central Plain and prehistoric Southeast Asia, noted by White (1988), addressed by the Sinocentric models? Huang He Central Plain metallurgy was characterized by complex, sophisticated piecemold-cast ritual containers and large-scale refractory systems, based on reverberatory furnaces (Barnard 1980; Tylecote 1996–1997). Higham's explanation for the marked differences between the Huang He metallurgy and the Southeast Asian metallurgy is based on a stimulus diffusion perspective.

> . . . it is argued that exposure to actual bronze imports [from Central Plain and Yangtze states], together with the spread of the idea that exposing certain coloured rocks to heat, it was possible to obtain this material for alloying and casting, were stimuli to the beginning of a local industry. . . . (Higham 1996, p. 312)

It was the newly developed Lingnan local or southern metallurgical tradition, more suitable for less-complex societies, which then spread to the Red and then the Mekong and Chao Phraya River valleys along preexisting networks of exchange, according to this theory.

A recent variant Sinocentric model for Southeast Asian bronze metallurgy presented by Ciarla and Pigott (Ciarla 2007; Pigott and Ciarla 2007) indirectly discusses one of the conundrums not addressed by Higham (1996) regarding the Southeast Asian metallurgical tradition. It has become evident, as the prehistoric bronze metallurgy in Russia has become better known (Chernykh 1992), that the products of Southeast Asian early metallurgy look very similar to Eurasian metallurgy to the north and west of the early dynastic states in the Huang He Central Plain (White 2000). Pigott and Ciarla acknowledge that "the 'southern metallurgical tradition' with its socketed implements, bivalve moulds, bangles, and founders' burials has more in common with the Eurasian steppes than Erlitou–Erligang China" (2007, p. 85). In addition to typological and technological parallels (e.g., use of bivalve molds), there are behavioral parallels of interring metalworkers with the tools of their craft—the "founders' burials"—found in metal age sites in Thailand (Higham 2008; Pigott 1999, p. 13) and in Eurasia (Chernykh 1992, p. 218). Whereas Higham has never addressed the Southeast Asian/Eurasian metallurgical parallels, Pigott and Ciarla's work contains a scenario to account for the Eurasian/Southeast Asian metallurgical similarities within a Sinocentric framework, drawing on data from the PRC that have become accessible in recent years.

In effect, while noting that much work is needed to demonstrate their proposal, Pigott and Ciarla's (2007) implied solution to account for the similarity between the Southeast Asian and Eurasian metallurgical traditions is that there was a ". . . 'Steppe techno-cultural package' transmitted from the eastern steppe metallurgical tradition to the Shang tradition and then southwards to the Southern tradition" (Ciarla 2007, p. 323, footnote 14). "Socketed tools (for example, ploughshares, several types of spade blades, adzes, chisels, and weapons) begin to appear regularly in the Shang inventory from the Erligang period (1600–1300) onwards" (Pigott and Ciarla 2007, p. 84). Bivalve molds appear in late Shang contexts at Anyang. They suggest that the steppe metallurgical techniques (bivalve molds) were being used to produce utilitarian tools and weapons (Pigott and Ciarla 2007, p. 84), while the piece-mold technology was used to cast the ritual vessels.

Pigott and Ciarla imply that the steppe and Shang metallurgical traditions must both have been transmitted via several steps to the middle Yangtze area and then the Ganjiang tributary, where the Wannian and Wucheng/Xin'gan cultures are "characterized by the hybridization of local elements with Shang-derived bronze technology and artifact types" (Pigott and Ciarla 2007, p. 80). The tributary provides trade connections to Lingnan in the southern PRC. The Zhou period site of Yuanlongpo is pointed to as a site in Lingnan that had both imported ritual vessels in the Shang-Zhou tradition and locally cast weapons and tools, as well as bivalve molds, and vessels that they suggest were crucibles based on their similarity in form to Khao Wong Prachan valley crucibles. The authors imply that only the utilitarian steppe-derived tradition was brought to the rest of Southeast Asia, which would explain why "links (of Southeast Asian metallurgy) to Steppe traditions appear to be more consistent" (Pigott and Ciarla 2007, p. 82):

> the piece-mould technology of the Shang–Zhou dynastic élites did not lend itself well to small-scale, community-based production among less socially complex cultural groups who over time were apparently mobile enough to expand out of southeastern China into new territories to the South. (Pigott and Ciarla 2007, p. 85)

In summary, whereas Higham portrays Lingnan as the creator of the Southeast Asian metallurgical tradition, Pigott and Ciarla imply that Lingnan was the final filter removing the "Chinese" technological traits from a steppe metallurgical tradition, enabling it to move to less-complex societies further south.

Critical Appraisal of Sinocentric Views of Earliest Southeast Asian Metallurgy

Sinocentric models for the initial source of Southeast Asian metallurgy can be critiqued on several grounds.

Selective Use of Chronological Data

In order for the proposed sequences and timing of transfers of metal technology to work, Sinocentric models minimally need the earliest Southeast Asian metallurgy to be younger than the appearance of the Chinese dynastic states that activated the exchange networks. Their discussions, in fact, rely on selective use of data, so that the early metallurgy in Southeast Asia appears to be younger than 1500 BC. Pigott and Ciarla (2007) need the early metallurgy in Thailand to be younger than the beginning of the Erligang (early Shang 1600–1300 BC), when steppe artifact types start appearing in Central Plain sites with some regularity (Pigott and Ciarla 2007, p. 84). For either proposed transmission sequence to truly work, the earliest metals in Thailand must be younger than those of Lingnan, where Higham (1996, p. 94) has argued that bronze metallurgy appeared during late Shang times (after 1300 BC). Therefore, proponents of Sinocentric models must either dispute (Higham 1996, pp. 9–13, 187, 1996–1997, 2002, pp. 133–134, 2009; Higham and Higham 2009; Higham and Thosarat 1998, p. 84) or ignore (Pigott and Ciarla 2007) evidence for early second millennium BC bronze in Southeast Asia.

Higham's most recent chronology advocates extreme selectivity, namely the "rejection of all previous attempts to date Southeast Asian prehistory radiometrically" (Higham and Higham 2009, p. 139). Arguing primarily from a new experimental program of shell dating from a single site, Ban Non Wat, he concludes that the Bronze Age began 1000 BC (Higham 2009; Higham and Higham 2009, p. 138). However, he does not undertake the vital and basic step of systematically cross-dating Ban Non Wat's relative ceramic sequence with any of the sites or regions noted above that have the earliest evidence for metallurgy. His dating, impressive methodologically though it may be, is applicable only to the florescence of bronze use in the immediate area of the upper Mun River valley (perhaps analogous to Henrich's (2001) "takeoff point" in cultural transmission), but not to the initial appearance of the technology in other parts of Thailand or Southeast Asia (cf. Henrich's (2001) "long tail" period of initial transmission).

The evidence for pre-1500 BC bronze in Thailand has been vigorously debated since the late 1960s (for example, Bayard 1996–1997; Bayard and Charoenwongsa 1983; Higham 1996, 1996–1997; Loofs-Wissowa 1983a, b; Solheim 1983; White 2008). White has consistently advocated early second millennium BC dating for the earliest bronze at Ban Chiang. Initially White's argument (White 1982, 1986) was based on conventional ^{14}C dates on charcoal from the site. But in response to the debate, White (1997) presented independent evidence from AMS dates on rice temper in burial pots to support early second millennium BC dating for bronze at Ban Chiang. White's (2008) review of pertinent AMS dates reaffirms the evidence for the early second millennium (c. 2000 BC) for the appearance of bronze at Ban Chiang. Bronze in prehistoric sites in Thailand around 2000 BC invalidates arguments that the early Chinese dynasties were the originating stimulus for the first appearance of bronze in Thailand, and this by itself disproves the Sinocentric models for the source of the earliest bronze in Thailand. That the Huang He Central Plain may have affected later periods of Southeast Asian metallurgy is, of course, a scenario worthy of further investigation (Ciarla 2007).

Selective Use of Technological Evidence

Sinocentric views are selective also in their use of available technological data. Proponents of Sinocentric models explicitly or implicitly reduce technology transfer to "... knowledge of the properties of copper and tin ore" (Higham 2004, p. 52). Sinocentric assessments of the sources for early metallurgy in Thailand do not fully examine characteristic components of Southeast Asian early bronze metallurgy, most notably the probable use of lost wax casting for making jewelry, the full significance of the hollow-core casting of sockets of adze–axes and spear points, and the distinctive common Southeast Asian refractory system. How to account for the presence of lost wax casting in Southeast Asia probably a millennium or more before its use in the Huang He Central Plain repertoire, where it did not appear until sometime in the mid-first millennium BC (Barnard 1996–1997), is not mentioned. (See also Weirong Zhou et al. (2009) for an even later chronology for the appearance of lost wax technique in China; but cf Davey 2009). Pigott and Ciarla do discuss the occurrence of bivalve molds in the Central Plain, southern PRC, and Thailand from contexts dating from the mid-second to mid-first millennia BC. But why the wide range of Shang innovations (nonsteppe implements such as unsocketed halberds, socketed plowshares, spades, or an unusual disk-shaped item from Yuanlongpo) made with bivalve molds in Shang and southern PRC contexts did not transfer to early metal-using contexts in Thailand along with the steppe-derived metallurgical complex is not addressed.

The Sinocentric views do not address how the early common Southeast Asian production system, based on internally heated small crucibles, could have emerged from the Shang system of metal processing that employed large immobile crucibles heated externally in reverberatory furnaces (Barnard 1980; Tylecote 1996–1997).

Pigott and Ciarla (2007, pp. 80–81) do allude, albeit indirectly, to the technological transfer of aspects of the refractory system of the later Khao Wong Prachan valley from the north. There are two components of their argument. First is their general view that a steppe-derived technological tradition co-occurred with the Shang-style tradition. This steppe-derived system employed bivalve molds and presumably a refractory system more suitable for processing the smaller amounts of metal for fabricating utilitarian artifacts, although no evidence is provided for the presence of a steppe-derived refractory system in the Central Plain (see also Linduff and Mei 2009, pointing out the lack of a utilitarian metallurgy in the Central Plain during Shang times).

The second part of their argument points to two examples of artifacts from peripheral parts of the PRC that are similar in shape to two Khao Wong Prachan valley refractory artifact types dating to the late second and early first millennia BC. At Yuanlongpo, a Zhou period (1100–800 BC) site in Lingnan that interacted with Yangtze cultures, one vessel type is proposed as evidence for a source of Khao Wong Prachan Valley crucible technology in southern PRC. However, no evidence is presented that these objects are anything other than bowls, no evidence is presented that they had dross or slag, or interior vitrification, or any other evidence for exposure to molten metal, a point acknowledged by Ciarla (2007). Ciarla and Pigott (2007) and Ciarla (2007) also suggest a possible northern but non-Shang source for the Khao Wong Prachan furnace chimneys at the site of Niuheliang in Lianging Province, in northeast PRC near the Korean border. This possible furnace chimney appears to be Erlitou or older (2300–1600 BC) in age, but outside and to the northeast of the Huang He Central Plain. They note that there is no evidence that furnace chimneys are typical of Eurasian steppe metal production systems and offer no evidence for cultural contact between this far northeast area and Southeast Asia.

The parallels suggested by Pigott and Ciarla in technological systems in Thailand and China, when examined in detail, are thus too tenuous in their metallurgical function and too dispersed in time and space to offer a convincing source for the Khao Wong Prachan valley metallurgical system. In addition, the source of the earlier common Southeast Asian crucible system is the one in need of explanation for those interested in the initial introduction of bronze metallurgy into the region.

Core/periphery Bias

Neither version of the Sinocentric approach references a theoretical framework. Yet it is clear from the lines of reasoning, the language employed, and the selection/rejection of evidence brought into their discussions that they are rooted in theoretical paradigms that perceive explanations of the past in terms of core/periphery dynamics at the scale of world-systems approaches (see the review in Hall and Chase-Dunn 1993).

> The world-systems model emphasizes the role of long-distance trade dominated by the core area as the main factor explaining both the political economy of the periphery and its trajectory of developmental change. (Stein 1999, p. 3)

This viewpoint is reflected in Higham's (2006, p. 19) recent summary statement, "The knowledge of bronze metallurgy may have reached Southeast Asia from the established states in China through the medium of exchange". But, setting aside the misfit of the chronologies, we ask whether a core-to-periphery model is an apt explanation for the initial transmission of bronze technology to prehistoric Thailand, viewing Thailand as the far periphery of state societies in the Huang He Central Plain.

World-systems approaches that emphasize core-to-periphery approaches to understanding the vast Bronze Age networks of peoples interacting in central and northern Eurasia have recently been criticized (Hanks and Doonan 2009; Kohl 2007, pp. 246–247, 2008). The mobile herding economies of this huge region, which developed based on a combination of subsistence choices and strategies, transportation innovations (horseback riding and wheeled vehicles), and metal technology, appear to have had their own dynamic, noncentric development for which world-systems approaches are proving inadequate interpretive frameworks. In particular, transferable technologies such as metallurgy provided different bases for intersocietal interactions, less controllable by political and economic cores or elites, than the exchange of goods and materials.

Chernykh (1992, pp. 300–301) argues, moreover, that in the case of metals, technology transfer often occurred in the reverse direction: the "uncivilized" periphery has, at times, provided technologically superior implements and technologies to the civilized core, such as when the technology for European and North Caucasian shaft-hole axes spread into Asia Minor. Similarly, he notes that in a later time frame of the first millennium BC:

> Chinese written sources speak directly of being repeatedly compelled to borrow technology and weapon forms from the "wild peoples" of the steppes and foothills of Central Asia. . . Chinese sources contain a painful acknowledgement of the superiority of the weapons of the nomadic hordes and the need to acquire them. (Chernykh 1992, p. 301)

Oversimplified Technological Transmission Models

By attributing the transmission of bronze technology to Southeast Asia to exposure to trade goods of more sophisticated societies and the idea of smelting, Sinocentric views underestimate the complexity of transferring metals technology from one society to a second society that has no prior experience with metal processing. Proponents of the Sinocentric models may argue that the kinds of details one would need to reconstruct sociotechnical systems, such as good metal production evidence from along the transmission routes proposed, are not available. But we argue that they bypass technological data that are available and do not take advantage of recent thinking on cultural and technological transmission (e.g., Boyd and Richerson 1985; see recent reviews in O'Brien 2008).

On closer inspection of the data, the Sinocentric diffusionary transmission scenarios—both the "stimulus diffusion" variant of Higham (1996, p. 312) and the "steppe metallurgy surviving cultural filters" variant of Pigott and Ciarla (2007)—do not satisfy. In particular, neither adequately accounts for the loss of Chinese technological characteristics during the transmission process. Higham's scenario does not explain how the distinctive technological choices and styles evident in the Southeast Asian metallurgical tradition could have arisen from the context of the Shang metallurgical tradition but leave no evidence of the technological choices and styles from the Chinese source. The loss of other characteristics of the Shang metallurgical tradition, such as highly decorated surfaces, tanged and other useful implements, and the refractory technology based on large externally heated crucibles in reverberatory kilns, is not dealt with. Pigott and Ciarla do point to the occurrence of steppe-derived bivalve molds for deep-socketed axes in Shang contexts; they also mention that bivalve molds were used for many new shapes, including casting unsocketed items and many new utilitarian items such as plows. Why were these Shang innovations on so-called steppe technology also completely lost by the time bronze reached Thailand, such that the early artifact repertoire in the Southeast Asian tradition ends up with only typical upper Eurasian artifact types and fabrication techniques? The source for several attributes that *are* characteristic of early Southeast Asian metallurgy, such as the common internally heated crucible, the limited though distinctive repertoire of artifacts (including metal jewelry, not found at all in Shang contexts), preference for certain deep-socketed tool forms over others, preference for binary tin bronze rather than a ternary copper–tin–lead alloy that was common in the Huang He Central Plain, lost wax casting, and the decentralized organization of production are not addressed.

A body of literature on the spread of culture and technology has grown during the past two decades and is providing many tools with which to examine "diffusion" and its current broader moniker "cultural transmission" (see reviews and articles in O'Brien 2008). Thinking has shifted away from assumptions that "exposure leads to spread" to fine-grained examination of social contexts for learning, evidence for practitioner networks, the roles of individual agents, impact of various kinds of biases on the shape and rate of transmission, as well as fuller appreciation that different kinds of cultural traits, such as a technology versus a belief versus a style, can transfer from one society to another by different processes (e.g., Killick 2004; Kim 2001; Kuhn 2004; Lemonnier 1986, 1992; Pétrequin 1993; Schiffer 2001a, b, 2008). Understanding transfer of complex technologies requires careful consideration of the context for social learning and the social relations in the community of practitioners (Van Pool 2008, p. 195). Careful attention paid to the technological choices in the various cultures along a proposed route of transmission will help avoid incongruous scenarios for technological transfer.

Recent studies of the cultural transmission of technological knowledge have focused on how recipient practitioners acquire and maintain new technological knowledge from donor practitioners. In one example, Bettinger and Eerkens (1999) examine the transmission of bow and arrow technology in Nevada and California, in light of Boyd and Richerson's (1985) concepts of "guided variation" and "indirect bias." In social contexts with limited or incomplete transmission between the donor and recipient practitioners, such as when recipients "copy" products but do not necessarily receive direct instruction, the products of the recipients have traits indicating experimentation with the new technology. The term used to describe the variability that arises with experimentation, “guided variation,” refers to the trial and error processes as individual practitioners work out their own interpretations of the process, guiding their practices by the successes and benefits to themselves. The end result is that a wide variety of technological choices and processes can be seen in the archaeological record of the recipient society in the early stages of technology adoption. When technology transmission is more complete or direct, such as might occur if practitioners from the source society moved into the receiving society and thoroughly trained members of the receiving society in the technological system, a much closer approximation of the donor technology will develop in the recipient culture. The phrase “indirect bias” has been used in these cases where the technological package is transmitted more completely, with little evidence for experimentation. The complete transmission results in a more homogeneous technological practice and more uniformity in the product line, relative to the guided variation context.

The general concept of cultural transmission and potential biases has been developed further in a variety of ways (Heinrich 2001; Mesoudi and O’Brien 2008a, b; O’Brien 2008), but for the purposes of this chapter we focus on the simple contrast: does the evidence of early metallurgy in Thailand suggest relatively complete and direct transmission with indirect bias, or incomplete and indirect transmission of bronze technology (e.g., emulating trade goods) with guided variation during the earliest stages?

An Alternative to the Sinocentric Model: The Rapid Eurasian Technological Expansion Model

In this section, we strive to investigate the sources for the earliest Southeast Asian metallurgy by prioritizing the study of its technological system. We assume that transmission of metal and metal artifact-production technology likely involved transmission of specific ways of accomplishing the many steps involved—technological choices and technological styles—from prospecting for ore to the creation of the finished artifacts. Thus, we build our study on a close evaluation of not only the chronology of the Southeast Asian metallurgical system within the greater Asian context, but also of the technology of the metallurgical system (described above) for which we seek precursors. We begin with a brief summary of East Asian metallurgy prior to its appearance in Southeast Asia.

Metallurgy in Eastern Eurasia Before 2000 BC

In the past two decades, an explosion of information on the prehistoric nomad groups in the former Union of Soviet Socialist Republics (USSR)(Anthony 2007; Chernykh 1992; Chernykh et al. 2004; Kohl 2007; Koryakova and Epimakhov 2007; Kuz’mina 2008; Linduff 2004a, b; also see Hanks and Doonan 2009 and Linduff and Mei 2009) has shown that copper-base technology has a rich history east of the Urals prior to the second millennium BC. Various instances of copper-base metallurgy dating within the third and even the fourth millennium BC in Asia east of the Urals (Linduff 2004b) demonstrate that knowledge of copper smelting was spread, albeit spottily, over a wide area of northern Asia from the Urals to the Pacific seaboard (Linduff and Mei 2009). Third and fourth millennium metalworking cultures have been found near ore sources, especially copper, but analyses show bronze alloys and gold also appeared in addition to copper working, when the minerals were available. Shared similarities between the artifact and technological repertoire across this swath suggest to Linduff and Mei (2009) that craft workers themselves must have moved in the vast cultural network.

Kohl (2007) has suggested that mobility across Bronze Age northern Eurasia was fostered not only by the search for pasture, cattle, horses, and other animals, but also by the search for metal resources. The socioeconomic context for metalworking in these mobile societies was quite different from classical state-based Bronze Age contexts. As Kohl notes, "... the herders of the steppes were self-sufficient, organized into partially autonomous/independent kin-structured groups that were capable of forming and dissolving alliances with related groups, and increasingly worked metals for eminently practical purposes" (Kohl 2007, p. 248). Even some groups of foragers and hunter-fishers adopted metalworking skills (Anthony 2007, p. 389; Chernykh 1992, p. 187).

One metal-rich area with an early and important history of metal-using cultures is the Minusinsk basin in southern Siberia, along with the Altai Mountains just south. This area had a sequence of metal-producing cultures beginning with the Afanasievo in the fourth millennium. About 100 metal objects, mostly of copper, have been recovered from Afanasievo contexts, one-fourth of which are tools such as flat axes and knives, ornaments (rings), with the remainder unfinished or unshaped fragments. During the late third millennium, the Okunevo and Seima-Turbino groups occupied these areas and employed a more developed metallurgy, including tin bronze. Subsequently in the second millennium, bronze-producing Andronovo groups appeared in this area (Anthony 2007; Gorsdorf et al. 2004; Hanks et al. 2007).

Other areas of East Asia have evidence for occasional copper exploitation in the third and possibly late fourth millennium BC, including Gansu (Majiayao culture, copper and tin bronze) and Huang He Central Plain (Longshan Period, unalloyed copper and bronze), although the details can vary by author (Linduff 2004b; see articles in Linduff et al. 2000; also see Linduff and Mei 2009), for a review of early metallurgy in the northwest PRC.

In summary, current evidence suggests that the knowledge of smelting copper was widespread, though rare and sporadic, across Eurasia during the third millennium BC in a range of sociocultural contexts. Some of the societies familiar with metal processing, such as Longshan, were settled and had evidence of incipient complexity. Nomadic pastoralists like the Afanasievo exploited the copper ores in southern Siberia at a low intensity. Other societies, such as those in Karelia, in the forest and forest-steppe zones of northern Eurasia, and the Surtandy culture of the eastern Urals, demonstrate that relatively noncomplex societies, including settled hunter-fishers, or smaller mobile groups, could mine and smelt copper and produce simple tools and ornaments when close to ore sources (Chernykh 1992, p. 187).

Metallurgy c. 2000 BC in Eastern Eurasia

Eurasian metallurgy showed rapid developments, shifts, and expansions in the period at the end of the third millennium BC (Chernykh et al. 2004, p. 24). Chernykh (1992) views these changes as the end of the Middle Bronze Age and the beginning of the Late Bronze Age when a new Eurasian Metallurgical Province emerged as the preceding Circumpontic Metallurgical Province collapsed. "What is clear is that during the Late Bronze Age peoples from more areas are extracting more ores and producing more metal tools and weapons of related types on a greatly expanded, nearly industrial scale across most of Eurasia" (Kohl 2007, p. 169).

In southern Siberia, the Okunevo culture probably learned about copper-base metallurgy from the Afanasievo (Chernykh et al. 2004, p. 28). However, while the rare Afanasievo metal artifacts are of unalloyed copper, gold, and silver, the Okunevo used both copper and tin bronze for knives, awls, and bracelets. Okunevo finds include one bronze-cast socketed spearhead, the earliest such spearhead this far east.

Seima–Turbino Metallurgy

Among the various cultural entities with metallurgical capabilities east of the Urals around the turn of the third to second millennium BC, one is particularly intriguing for the purposes of this chapter—the one Chernykh calls (1992, pp. 215–234) the "Seima–Turbino transcultural phenomenon."

> The Seima–Turbino phenomenon. . . stands out from other communities in its metalwork. Three main categories of object lend these assemblages a distinctive appearance: socketed spearheads, socketed axes and knife-daggers. . . they are all extremely rare in sites of other cultures: the majority of these artefact types are characteristic only of Seima–Turbino burial grounds. (Chernykh 1992, p. 218)

David Anthony (2007, pp. 434–444) has commented, "the tin-bronze spears, daggers, and axes of the Seima–Turbino horizon were among the most technically and aesthetically refined weapons in the ancient world, but they were made by forest and forest-steppe societies that in some places. . . still depended on hunting and fishing."

This Seima–Turbino phenomenon, recently dated to the late third millennium (Chernykh 2009, p. 4; Hanks et al. 2007), is noteworthy for this chapter for several reasons: (1) it is recognized by characteristic assemblages of copper-base artifacts, which bear a close resemblance to the suite of earliest bronze artifacts in Thailand (Sherratt 2006, p. 43); (2) one of its signature tin-bronze artifacts is the thin-walled celt-axe (Fig. 28.4a), a key innovation of the late Bronze Age that is strikingly similar to the socketed implement from Non Nok Tha (Fig. 28.2c); (3) it is considered to have originated in the Altai Mountain area and almost instantly (in archaeological time)

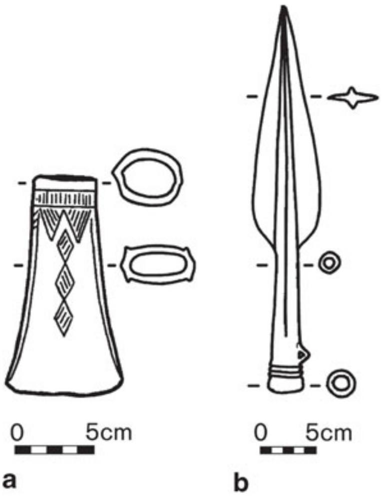

Fig. 28.4 Typical Seima–Turbino hollow-core cast implements. **a** Deep-socketed adze–axe from Rostovka cemetery (Adapted from Chernykh 1992, p. 221). **b** Socketed spear point with single-process cast socket from Seima cemetery (Adapted from Chernykh 1992, p. 219)

moved west as far as Finland, a distance of several thousand kilometers (Fig. 28.1); (4) outside of the Altai, the Seima–Turbino metal assemblage is found in deposits of other traditions, with evidence that the metal technological system was adopted by other cultures, but without a complete migration of the source culture and population; and (5) scholars have argued that it was the Seima–Turbino metals technological system that was an important source for the late third millennium bronze in the Qijia culture of Gansu (Fitzgerald-Huber 1995; Mei 2003).

The technological system of Seima–Turbino metallurgy has additional noteworthy characteristics. Seima–Turbino metals assemblages east of the Urals are predominantly binary-tin bronzes, consistent with their access to the rich tin and copper sources in the Altai region. To the west of the Urals, the same artifact types are more likely arsenical copper, showing that the casting repertoire was undertaken with local resources. Their technological system also employs lost wax casting (to make the figurative flourishes on the hilts of knives), and bivalve molds found in Seima-Turbino sites demonstrate that casting occurred at sites far from ores.

The Seima–Turbino technique of casting blind sockets (Chernykh 1992, p. 191) in spearheads and particularly adze–axes (Fig. 28.4a, b) by suspending a core in the casting between the two mold halves is considered a remarkable innovation in the history of metallurgy (Childe 1954; Koryakova and Epimakhov 2007, p. 39; Sherratt 2006, p. 43). To the west, at contemporaneous sites like those of the Sintashta culture in the southern Urals, as well as in the Middle East and Mediterranean, sockets on spear points were made by forging a metal sheet around a socket form (Anthony 2007, p. 444; Sherratt 2006, p. 44). Hollow-core cast, socketed spear points, and axes appeared in western Europe only several centuries later in the Late Bronze Age. V. Gordon Childe (1954) recognized the technological importance of hollow-core casting of Eurasian “socketed celts,” especially for woodworking. He commented that they were superior to flat axes because they could be more securely hafted, and superior to shaft-hole axes for their longer working edge and more economical use of bronze. The latter point could be one key to the desirability and transferability of the hollow-core adze–axe technology to the woodlands of upper Eurasia, far from ore sources. Childe also stated (1954, p. 19) "[a] supply of tin bronze is probably a prerequisite for the postulated advance in core-casting." Once casting the socket is mastered, production of socketed implements will be considerably easier and faster than when forging one, which would require a lengthy and strenuous process of several rounds of annealing and hammering it to shape. Childe further commented on the challenge of positioning the suspended core that formed the socket, requiring an innovation such as inserting metal-spacing pins that would be incorporated into the cast tool, or wax plugs to hold the core in place.

Seima-Turbino Expansion

Although much has been made of the expansion west to east of metalworking pastoralists, such as the Andronovo, across the Eurasian steppe zone during the late Bronze Age, the apparently pre-Andronovo east (originating in the Altai) to west expansion of the Seima–Turbino phenomenon occurred in the forest and forest-steppe zones. This technological system was thus not of steppe pastoralists but rather of forest-oriented groups who may have been mobile hunter-fishers and/or warriors in addition to metalworkers. Such an orientation toward the forest is compatible with the signature Seima–Turbino socketed adze–axe, recognized as most suitable as a woodworking tool (Childe 1954). The distribution of Seima–Turbino cemeteries closely follows rivers (Koryakova and Epimakhov 2007, p. 108; Kuz'mina 2004, p. 51). The metallurgical (including production) evidence from Seima–Turbino sites along waterways across the forest zone of northern Eurasia suggests that an exchange system not only of metal (possibly especially tin), finished artifacts, but also of metalworkers who developed local resources (Kuz'mina 2004, pp. 51–52) emerged along this route.

The consistent morphology and casting technology of Seima-Turbino assemblages, even considering local adaptations such as use of local ores and the loss of some decorative elements, correspond well with a fairly direct and complete transmission of the technological system. The social and technological characteristics that facilitated rapid transmission of the Seima–Turbino metallurgical system across thousands of kilometers are not as yet well understood (cf. Anthony 2007, p. 447; Kohl 2007, p. 169). Various writers seem to have different explanations of how and why such a distribution came about, variably bringing militarism, trade, traveling metalworkers, élite emulation, transportation by horse, and other factors into proposed scenarios (Anthony 2007, p. 443, 446, 447; Chernykh 1992, pp. 227–228; Chernykh et al. 2004; Kohl 2007, p. 169; Koryakova and Epimakhov 2007, p. 108; Kuz'mina 2004, pp. 51–52).

What seems clear is that the geographical spread of Seima–Turbino hollow-core casting involved the movement of highly competent metalworkers to regions outside their home territory; trade is not a sufficient explanation for the extant evidence (but cf. Koryakova and Epimakhov 2007, p. 110). Further elucidation of the transmission process will benefit from explication of the refractory technology throughout the Seima–Turbino distribution. A portable low capital, segmented production system, such as we describe for early Southeast Asian bronze production, may help account for the rapidity with which the Seima–Turbino technological system could be adopted over such a vast region in a short period of time.

Thailand and the Seima–Turbino Transcultural Phenomenon

The typology, alloys, and object formation techniques (in particular, hollow-core casting of socketed adze–axes and spear points, and lost wax casting) of the early bronzes from the Seima–Turbino repertoire appear markedly similar to the artifacts, alloys, and formation techniques found in the earliest metals of prehistoric Thailand. As Sherratt (2006, p. 48) notes, the Seima–Turbino method of manufacturing socketed artifacts "provides a plausible starting point for the tradition of early Chinese and Southeast Asian hollow-cast metallurgy, beginning in the early second millennium." The earliest copper-base materials from Southeast Asia (e.g., Table 28.1; Fig. 28.2) also resemble Eurasian copper-base assemblages generally (bangles, arrowheads, fishhooks). Although investigation of the Seima–Turbino transcultural phenomenon has focused on its spread westward in upper Eurasia, there is no reason to assume that the "impulse to expand" occurred only in one direction. The dating of the early prehistoric metals in Thailand to the early second millennium BC meshes well with the possibility of another extremely rapid expansion of the Seima–Turbino technological system to the south.

The above discussion of the nature of the expansion of Seima–Turbino metallurgy in northern Eurasia lays the groundwork for understanding possible expansions in other directions. To help envision the expansionary ethos of the Late Bronze Age, Kohl (2007, pp. 169–179) postulates a "gold rush model," with many groups like Seima–Turbino seasonally and opportunistically prospecting for ores, extracting them with low-technology procedures, and hauling them away. Exchange networks expanded, and metal processing became common even in ordinary households at sites far from ore sources.

If Kohl is right, then a Seima–Turbino extension south and east from the Altai simultaneous with its extension west is a logical possibility, which we may seek in the archaeological evidence. In the next section, we review such evidence. But first we review what we propose are some basic attributes of the donor sociotechnical system that could also contribute to the rapid dispersal of metal technology: (1) highly mobile economies; (2) widely dispersed technological knowledge; (3) nonexclusive access to the technology, possibly fostered by metalworkers having neither extremely high nor extremely low status, or being controlled by a dominant élite jealous of access to metallurgical knowledge; (4) modest social differentiation and a relatively unstratified society; (5) aggressive search for natural resources supports exploration of new lands for ore; (6) small-scale, flexible, and portable technological system, with small, probably internally heated crucibles and small impermanent refractory installations using local resources for refraction and processing; (7) despite a preference for tin bronze, familiarity with various alloys allowing use of local ore sources; (8) experience in a segmented metal artifact-production system; (9) warfare not so rampant that people and technologists do not interact; and (10) small related groups, each with technological expertise, moving independently.

The homogeneity of the early metallurgy practiced in prehistoric Thailand and its noteworthy similarity to the Seima–Turbino repertoire argue that knowledge of metal production and working was transmitted in a relatively direct and complete manner by experienced practitioners who were trained in the Seima–Turbino technological system. If the transmission was incomplete and indirect, one would expect extensive individual experimentation (guided variation) in the early Southeast Asian copper-base repertoire, of which there are few signs. Might prospecting metalworkers have made their way down the valleys and rivers along the eastern rim of the Himalayan Plateau, seeking copper and tin and ultimately reaching Thailand? We turn now to the evidence, and the gaps in the evidence, for such an occurrence.

Hypothesis for the Routes of the Transmission of Bronze Technology from Southern Siberia to Prehistoric Thailand

This section begins with five points. First, the early metals in Thailand bear a remarkable resemblance technologically and typologically to Seima–Turbino forest bronze assemblages in particular, and to southern Siberian (including Okunevo) bronze metallurgy at the end of the third millennium BC generally. Second, the resemblance suggests a relatively direct and complete transmission of the technology in alignment with the “indirect bias” concept. Third, if this is correct, the transmission must have been very rapid, since the dating of the earliest metals of Southeast Asia is close in age to Seima–Turbino, based on current evidence (cf. Hanks et al. 2007 and White 2008). Fourth, a southern extension of the Seima–Turbino metallurgical system has, in fact, already been identified in Gansu (Fitzgerald-Huber 1995; Mei 2003). Fifth, the archaeological data in the terrain between the Gansu and Thailand are not sufficient to allow us to conclusively evaluate the proposal that the early bronze metallurgy in Southeast Asia was directly derivative of the Altai tradition. Nevertheless, a transmission route can be posited at the very least to stimulate directed archaeological research to test the proposal.

Northwest PRC

South of the Altai Mountains, Xinjiang and the Gansu corridor have been proposed as key links in the transfer of bronze technology from western parts of Eurasia to the Huang He Central Plains (An Zhimin 1993, 1998, 2000; Ciarla 2007, p. 306; Fitzgerald-Huber 1995; Higham 2002, p. 115; Linduff 2000; Mei 2003; Pigott and Ciarla 2007, p. 76, 80; Shuyun and Rubin 2000a, b).

The general area, particularly eastern Qinhai and Gansu, is rich in nonferrous mineral resources. There is as yet no compelling evidence for a late third millennium Seima–Turbino metal tradition in Xinjiang.

Qijia in Gansu

However, in neighboring Gansu and Qinghai provinces there is the remarkable Qijia culture where metallurgy reportedly of Seima–Turbino derivation has been found (Chernykh 2009, p. 7; Fitzgerald-Huber 1995; Mei 2003). Beginning in the late third millennium BC and extending into the early second millennium (Thorp 2006, p. 54; Mei (2003, p. 34) gives 2300–1700 BC), the Qijia culture is notable for its relatively numerous metal finds of more than one hundred copper, arsenical copper, and bronze artifacts. Finds include knives, awls, rings, mirrors, plaques, a flat axe, and several artifacts reflecting Seima–Turbino types and casting techniques, in particular two deep-socketed axes, and a socketed spear point. Fitzgerald-Huber (1995) first put forward the argument that the Qijia metals, particularly the deep-socketed axes and certain knives, indicated close contact with the Seima–Turbino metalworkers. Mei (2003) discusses more recent finds, particularly a socketed spear point with "diagnostic" attributes identical to classic Seima–Turbino spear points. Mei's (2003, 2009) overview of the evidence further indicates that numerous interactions, including a range of metallurgical borrowings, probably occurred among societies in Gansu, Xinjiang, and southern Siberia in the late third to early second millennium BC.

As reviewed in detail in Fitzgerald-Huber's (1995) article, Qijia sites reveal a noteworthy combination of (a) material remains (metals), faunal remains (cattle, horse, and donkey), and mortuary practices derivative of southern Siberian nomadic cultures, most abundantly and clearly but not exclusively the Seima–Turbino, with (b) indigenous practices (regional ceramic styles, sedentary agriculture), and (c) some eastern attributes (scapulimancy and millet cultivation). To account for the archaeological evidence, she argues for a:

> . . . persistent form of contact between the two groups and the more or less sustained presence in the vicinity of the Qijia settlements of northerners linked. . . to the Seima–Turbino. . . We can imagine that in time the Qijia accustomed themselves to their visitors from the north and to matters of metal technology, adapting this technology to their own purposes. . . . (Fitzgerald-Huber 1995, pp. 51–52)

The route by which Seima–Turbino groups connected with Qijia may eventually be found in Xinjiang, but Fitzgerald-Huber (1995, p. 51) says "a somewhat more probable route may have led south along the Mongolian Altai and eventually have followed the Edsingol to the Gansu Corridor."

Another remarkable point about the Qijia is that not only did they maintain wide-ranging contacts with neighboring cultures (Fitzgerald-Huber 2003; Mei 2003), but also a Qijia "colony" settlement has been identified at Damiaopo, over 1000 km to the northeast of the main area of Qijia settlement in Gansu:

> The main reason the Qijia journeyed the long distance to the northeast, and in some cases settled there. . . almost certainly resides in. . . the circumstance that the Qijia were the source

> of metal objects. . . Moreover, the abundance of easily accessible copper ore in the immediate vicinity of several Qijia settlements would suggest the likelihood that the raw material of copper. . . became itself a commodity of trade with the Northern Zone, destined for the production of metal objects by sedentary communities in that area. (Fitzgerald-Huber 1995, p. 36)

This long-distance colony provides additional evidence that Bronze Age groups were willing to move to distant regions and "set up shop" while maintaining contact with the home base over long distances with few or no intermediary settlements.

The Qijia evidence provides numerous insights into the Seima–Turbino phenomenon. It supports the argument that competent metalworkers moved into a territory occupied by other cultures and were apparently assimilated by the indigenous groups. They provided expertise and probably training of locals in metalworking, including casting implements characteristic of the metalworkers' source culture (deep-socketed implements and certain knives). They probably provided expertise in the mining and smelting of local ores. They and/or other northern pastoralists also brought a suite of domesticated animals, including the horse, which the hosts assimilated. Although the Qijia hosts were sedentary agriculturalists, they conducted extensive trade and sent out colonizing groups to great distances from the home territory, probably in relation to metal exchange. In those distant colonies, they may have provided raw material for sedentary village societies in areas without local mineral resources and perhaps also conducted secondary processing (melting and casting). The assimilation was prosperous and enduring, without marked evidence for warfare.

Huang He Central Plain

The turn of the third to second millennium BC finds only traces of copper-base artifacts in the Huang He Central Plain. The cultural period is terminal Longshan horizon, with Erlitou beginning c. 1900 BC. Longshan sites in the Central Plain have a few copper and bronze remains. Casting, forging, and some alloying were practiced, but most casting (including awls and other miscellaneous small pieces) was done in univalve molds. One flat axe with a hole was cast in a bivalve mold (Yan 2000, p. 106). There are no metal weapons, agricultural tools, or bangles. One small copper bell was found in a late Longshan burial at Taosi.

With Erlitou, the picture emerging is that, aside from the ubiquitous small artifact set (awls, fishhooks, arrowheads, and small blades), large copper-base artifacts generally do not reflect direct Seima–Turbino or any other Eurasian steppe prototypes (Chernykh 2009; Mei 2009). Rather, the earliest larger distinctive Erlitou castings (larger bells similar to the Taosi example, plaques with inlaid turquoise, eventually vessels) appear to be of locally derived shapes. Socketed items are absent, and bivalve molds are used, but for flat castings (Yan 2000, p. 109). If Erlitou bronze casting was influenced by upper Eurasian metallurgies, perhaps only a few components were adopted (e.g., smelting ores and casting), but experimentation ("guided variation") with indigenous shapes and purposes was important in the transmission process (Chernykh 2009; Mei 2009). Most discussions imply that metal artifact production was a restricted activity controlled by and for the élite in the emergent state (for example, Linduff 2000, pp. 20–21; Linduff and Mei 2009; Mei 2009). Although from a later context, Thorp (2006, pp. 168–169) notes for Shang that bronze utilitarian tools are found in workshop debris, as are bone and shell tools. He also notes that Shang foundries produced utilitarian bronze artifacts, but that was clearly not their main function.

Details of the refractory aspects of the technology would assist in ascertaining whether Erlitou metalworkers maintained two levels of metallurgy, one for élites and another for the common folk or utilitarian items, producing more Eurasian-looking artifacts (perhaps differentiated in crucible scale and workshop location). In any case, at present we cannot point to close parallels in Erlitou contexts for the earliest evidence of bronze metallurgy in Southeast Asia, the hollow-core cast spear head and adze, lost wax cast bangles, and small spouted crucibles.

Continued investigation of possible sources for Erlitou copper-base metallurgy in Gansu and in pastoral societies in areas north and west of the Huang He Central Plain is an important endeavor. For the purposes of this discussion, however, the Erlitou metallurgy lacks signature Seima–Turbino copper-base socketed forms, especially the suspended-core socket types, found in the Qijia and southern Siberian traditions. This absence further undermines arguments that the Huang He Central Plain is a likely source for the earliest Southeast Asian metallurgy in the early second millennium BC.

Routes South—A Brief Proposal

Let us accept for the purposes of discussion the existence of at least an offshoot of the Seima–Turbino metals technological tradition in the Gansu corridor at the end of the third millennium BC in the Qijia culture. The presence of horses in Qijia suggests a means of long-distance transportation that could assist in the rapid transport of the bearers of metals technology. Did Seima–Turbino metallurgy stop its southward movement there? Archaeological data in the lands between Gansu and Thailand (western Sichuan and Yunnan) are sparse, especially to the scholar who does not read Chinese. Nevertheless, one can glean some possibilities from the literature.

First, is there any evidence that cultures in Gansu interacted with Sichuan to the south in prehistoric times without going through the Huang He Central Plain? Yang Meili (2002 as translated by Lothar von Falkenhausen 2006, p. 213) says:

> . . . communication from southern Gansu to northern Sichuan proceeded first downstream along the Bailong River and then joined the main road along the Jialing River. Archaeological surveys along the Bailong River have revealed numerous prehistoric sites of the Dadiwan, Majiayao, Qijia, and Siwa [Siba] cultures; Qijia and Siwa sites, in particular, are distributed very close to northern Sichuan. . . .

In short, apparently the Gansu–Sichuan connection was present even prior to Qijia times, in pre-metal periods. Prehistoric avenues of communication and contact could have run along river courses (Fig. 28.5), especially in rugged areas like the eastern

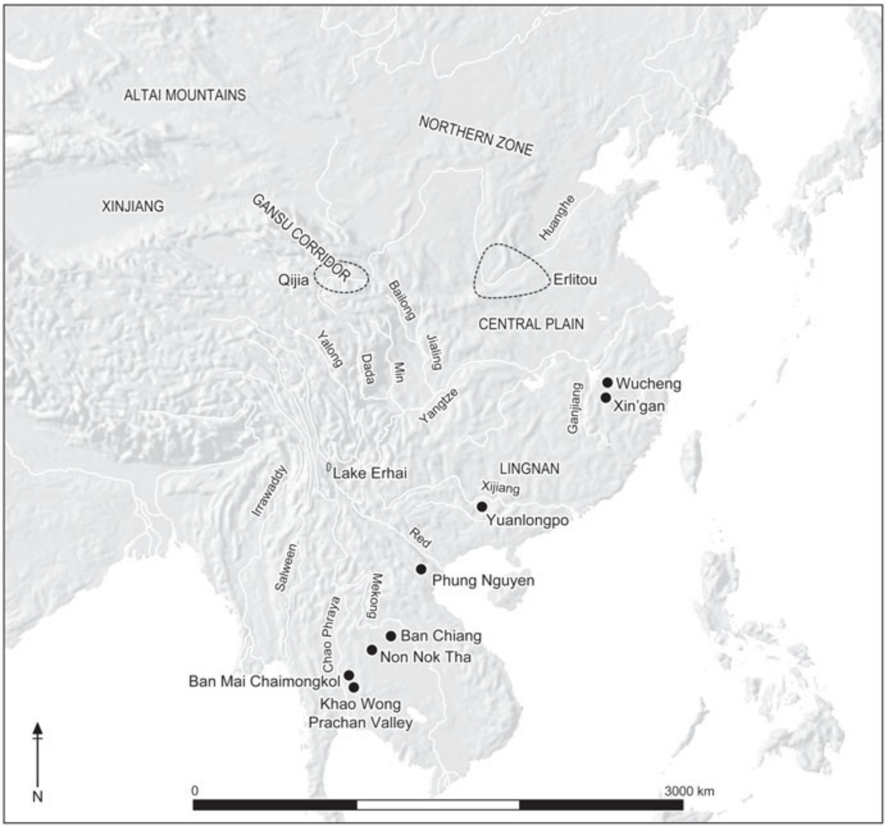

Fig. 28.5 Map of eastern Asia showing major sites, cultures, geographic regions, and rivers mentioned in the text

rim of the Himalayan Plateau. Moreover, as Seima–Turbino-trained metalworkers apparently followed river courses in forested areas of upper Eurasia, it is reasonable to propose that they would look along river courses as possible routes south. The Jialing River provides access to the relatively flat Sichuan Basin and Chendu Plain, entering the Yangtze at Chonqing.

There is less evidence for a c. 2000 BC Sichuan–Yunnan connection, but hypotheses can be formulated on the basis of evidence in later periods. Yunnan is separated from Sichuan by quite a rugged terrain. Nevertheless, during the first millennium BC, the connection of northwest Yunnan to Sichuan, Gansu, and the central Asian steppes is fairly clear-cut. Murowchick notes:

> ...the Bronze Age cultures of northwest Yunnan shared close affinities with the semi-sedentary and nomadic cultures of western Sichuan, and possibly with contemporaneous cultures of the Gansu–Qinghai plain and the central Asian steppes... Besides the distribution throughout this area of stone slab (cist) graves similar to some of those just described in Yunnan, a number of specific bronze artifact types suggest either close cultural contact across this wide area, or the transmission of material goods through intermediaries.... (Murowchick 1989, pp. 117–118)

A more extended discussion of western Yunnan's early connections to the north through Sichuan to the Eurasian steppes is provided by Chiou-Peng (1998, 2009). She stated (1998, p. 299) that the entire area formed a distinct cultural continuum, sharing technology and art as well as a mortuary tradition. It is clear from Chiou-Peng's work (1998, 2009) that the western axis of culture and communication was present from Lake Erhai to the Northern Zone during the second and first millennia BC. Some affinities noted with Qijia and even Majiayao ceramics argue for connections at least by the early second millennium BC (Chiou-Peng 1998, p. 295; Chiou-Peng 2009, p. 83). The Lanchang-Nu Corridor (upper Mekong and Salween rivers) has produced stone and copper-base adzes as well as stone molds and slag thought to be from the second millennium BC. The earliest date for the establishment of such north–south communication routes through Yunnan remains to be determined. Once in the Lake Erhai area, there is easy access to both the Mekong and the Red River drainages, and hence, in theory, to Northeast Thailand and the Bac Bo region of northern Vietnam, two areas where the earliest Southeast Asian copper-base artifacts are found.

For the purposes of developing a transmission model consistent with the technological and chronological evidence, we therefore hypothesize that metalworkers trained in the Seima–Turbino metallurgical system traveled along this western route c. 2000 BC, bypassing the Huang He Central Plain. This model sees extremely rapid dispersal of metalworkers with Seima–Turbino training, not only to the west from the Altai to Finland, as has long been recognized, but to the south as well. These metalworkers presumably actively sought metal resources, so metal-rich Southeast Asia would be attractive. As their social ethos apparently facilitated long-distance travel and their assimilation with other societies, they presumably trained locals in the fundamentals of their technology, and those locals may have carried it forward and possibly further afield.

The proposed route of communication from upper Eurasia to Yunnan along the eastern edge of the Himalayas, of great time depth, and bypassing the Huang He Central Plain, is not a new idea. Watson (1971, 1985, 1992) made similar observations more than 40 years ago. He also pointed out the similarities of the Hiamenko and Huang He socketed axes to inner Asian and Siberian prototypes (Watson 1971, p. 103), and was impressed with the earlier presence of lost wax casting outside of the Huang He Central Plain.

Although the rapidity and directness of the technological transmission from southern Siberia to the middle Mekong Basin may at first glance seem astonishing, the remarkable similarity of the early Southeast Asian metals to the Seima–Turbino technology and artifact repertoire argues that transmission was indeed both rapid and direct. The core Seima–Turbino and southern Siberian technological, and many typological, elements are all present—hollow-core casting of socketed implements in a single process, the artifact repertoire of deep-socketed adze–axes, socketed spear points with midrib, bangles, fishhooks and arrowheads, preference for tin bronze with minimal post-casting treatment, bivalve molds with suspended cores, and lost wax casting. Not found are Seima–Turbino decorative elements and certain kinds of knives, but these aspects may have been filtered out (selected against) in Gansu, where many are also missing.

In contrast, the metallurgy of Huang He Central Plain continued to receive input into its metallurgical system through interactions with and borrowing from the nomadic groups in the Northern Zone (Pigott and Ciarla 2007), resulting in the Shang-period appearance of suspended-core castings of deep-socketed axes. The evidence from Thailand, on the other hand, suggests an initial transmission occurred during a brief and limited period. Thereafter, the prehistoric Southeast Asian metalworkers maintained and eventually elaborated the same technological regime and style they had adopted initially. After 1500 BC, the Khao Wong Prachan valley technological system emerged, although whether it is a local innovation or a transmitted one, perhaps from areas north (Ciarla 2007; Pigott and Ciarla 2007), is not yet clear. Either way, its finished product repertoire bears some evidence of continuity of technological style with the earlier tradition in the continued use of cast blind sockets on adze–axe-like items, even if they are diminutive and possibly nonutilitarian implements. Finally, the similarity of the early Southeast Asian copper-base artifacts to the Seima–Turbino/Qijia technological system, together with lack of evidence for input from the slightly later Andronovo or Siba technological systems (that had a wider range of forms and greater use of forging, for example, of bangles: Chernykh 1992, p. 213), supports timing of transmission of bronze metallurgy to Thailand to a pre-Andronovo period of technological expansion, which would be also compatible with a date around 2000 BC.

Conclusions and Future Research Priorities

This chapter proposes a new interpretation for the source of the earliest bronze metallurgy in Southeast Asia. Drawing on cultural transmission approaches, a technological transmission argument is developed that incorporates current evidence on metal technological systems in Eurasia, social contexts for transmission, and current chronological evidence from Southeast Asia and Eurasia for the earliest appearance of metalworking. This evidence points to southern Siberia as the main source of the Southeast Asian metallurgical system in the early second millennium BC. In particular, characteristic traits of the Seima–Turbino metallurgical tradition of tin-bronze alloys, single-process hollow-core cast deep-socketed adzes and spear points, and lost wax casting of ornaments appear in Southeast Asia, particularly prehistoric Thailand, around 2000 BC. The limited repertoire of the early Southeast Asian metal artifacts is therefore seen as a product of relatively direct and complete transmission of the southern Siberian technological system, not as a product of gradual down-the-line filtering out of Sinitic forms and technologies at the periphery of Huang He states as some (Pigott and Ciarla 2007) have argued. Such rapid transmission of the southern Siberian metallurgical system may appear at first glance remarkable. But considering that other rapid long-distance transmissions were associated with other areas receiving a Seima–Turbino technological package at about the same time, the possibilities proposed seem worthy of further study. The Southeast Asian example may help prehistorians reassess gradualist assumptions for technology transfer in prehistoric times. How metallurgy got to Thailand is, we propose, a story that defies traditional archaeological gradualist expectations and provides new insights into prehistoric events, societies, and processes.

However, there are vast gaps in archaeological data between the Eurasian steppes and Southeast Asia that need to be filled before the argument presented here can be considered demonstrated. We hope that filling those gaps can be a priority in the future. The most exciting archaeology of the next decade in eastern Asia may be along the river systems extending out of the southeastern foothills of the Himalayas. In addition to simply more archaeology, particularly along the major drainage systems of southern and western PRC, two immediate efforts would contribute greatly to the investigation of the sources of metallurgy throughout Eurasia: (1) more detailed reporting, technological analysis, and publication of refractory components of metals technology; and (2) historical linguistic research on vocabulary related to metals and metal artifact production in eastern Asian languages.

From our point of view, the critical question concerning the source of bronze technology in Southeast Asia revolves around the source for the Southeast Asian metal refractory technology. Publication of crucible evidence has been neglected by archaeologists working in East Asia. At best, site publications mention the presence of crucibles, but provide few illustrations and no technical analyses of fabric, residues, vitrification, or other evidence of use without which the role of the crucibles cannot be meaningfully judged. Nonetheless, it is suggested here that when metals technology is transmitted, successful transmission of refractory technological style is probably a crucial component. Thus, refractory technology is the key to determining the source of Southeast Asian metallurgy, including both the Sinocentric and the rapid Eurasian technological expansion models. In particular the Seima–Turbino refractory technological system needs to be reconstructed across its range to see if the type of mobile, “one crucible serves all molten metal needs” model we find in Northeast Thailand was a part of the Seima–Turbino technological package, facilitating its rapid spread. The refractories used to produce utilitarian and local items in Huang He and Yangtze basins, as well as Lingnan and Bac Bo need to be identified, scientifically studied, and published. In addition, historical linguistics, physical anthropology, and faunal studies, in particular of the distribution of domesticated horses, are needed in order to holistically understand the nature of the prehistoric links between southern Siberia, western PRC, and Southeast Asia.

In the end, we will consider this chapter successful if it stimulates not only debates but also research. Not only should researchers look for data that can clarify the north (Gansu) to south (Sichuan–Yunnan–middle Mekong Basin) cultural interactions in prehistoric times, but also excavate, analyze, and publish (with illustrations!) well-dated in situ metallurgical evidence, including crucibles, smithies, furnaces, metal processing by-products, and analytical data. Only with the publication of these kinds of data, along with the application of up-to-date technological transmission concepts, will we begin to understand how Southeast Asia acquired its distinctive metallurgical tradition.

Addendum

Since the text for this chapter was published in White and Hamilton (2009), pertinent new chronometric data have been published (Higham et al. 2011). Although some chronological details for the authors' views may change with future reassessments, they stand by the technological and theoretical arguments presented here. They also emphasize the need to test their model and hypotheses with new archaeological data from southwest People's Republic of China.

Acknowledgments We thank Victor Mair for his enthusiastic mad-dash investigation sparked by a simple email request for references on archaeology in Yunnan and Sichuan to help sort out a possible link from Yunnan to Gansu c. 2000 BC. Thanks to all who answered Victor's emails to them on this topic. Constructive comments from Elisabeth Bacus, Roberto Ciarla, Robert Ehrenreich, Chureekamol Eyre, Victor Mair, Ben Marwick, Vincent Pigott, Oliver Pryce, Ben Roberts, Tim Taylor, Christopher Thornton, and Sarah Wright on previous drafts greatly improved the quality and content of this chapter. We gratefully acknowledge Ardeth Abrams, who prepared the illustrations. Anonymous reviewers have assisted us in strengthening both the arguments and the presentation. Thanks to Robert Murowchick for sending Joyce White his dissertation almost 20 years ago. And we are grateful to Surapol Natapintu for permission to use an illustration of the Ban Mai Chaimongkol bronze bar and to Bill Solheim for permission to use a drawing of WOST. Of course, any errors in scholarship are solely the authors'.

References

An Zhimin. (1993). Shi lun Zhongguo de zaoqi (On early copper and bronze objects in ancient China (in Chinese). *Kaogu (Archaeology)*, *12*, 1110–1119.

An Zhimin. (1998). Cultural complexes of the Bronze Age in the Tarim Basin and surrounding areas. In V. H. Mair (Ed.), *The Bronze Age and Early Iron Age peoples of Eastern Central Asia* (Vol. 1, pp. 45–62). Philadelphia: Institute for the Study of Man.

An Zhimin. (2000). On early copper and bronze objects in ancient China. In K. M. Linduff, H. Rubin, & S. Shuyun (Eds.), *The beginnings of metallurgy in China* (Vol. 11, pp. 29–49). Lewiston: Edwin Mellen. (Chinese Studies).

Anthony, D. W. (2007). *The horse, the wheel, and language: How Bronze Age riders from the Eurasian steppes shaped the modern world*. Princeton: Princeton University Press.

Bacus, E. A. (2006). Social identities in Bronze Age northeast Thailand: Intersections of gender, status and ranking at Non Nok Tha. In E. A. Bacus, I. C. Glover, & V. C. Pigott (Eds.), *Uncovering Southeast Asia's past: Selected papers from the 10th International Conference of the European Association of Southeast Asian Archaeologists* (pp. 105–115). Singapore: National University of Singapore Press.

Ban Chiang Project. (n.d.). The Ban Chiang Project Metals Database: Homepage. University of Pennsylvania Museum of Archaeology and Anthropology. http://seasia.museum.upenn.edu/metals/Web/index.html. Accessed 31 July 2009.

Barnard, N. (1980). The origins and development of metallurgy in China, with special reference to the crucible. In H. H. E. Loofs-Wissowa (Ed.), *The diffusion of material culture: 28th International Congress of Orientalists, Proceedings of Seminar E, Canberra, January 1971* (pp. 215–263). Asian and Pacific Archaeology Series No. 9. Honolulu: Social Science Research Institute, University of Hawaii at Manoa.

Barnard, N. (1996–1997). The entry of *cire-perdue* investment casting, and certain other techniques (mainly metalworking) into south China and their progress northwards. In F. D. Bulbeck & N. Barnard (Eds.), *Ancient Chinese and Southeast Asian Bronze Age cultures. The Proceedings of a Conference Held at the Edith and Joy London Foundation Property, Kioloa, NSW, Australia, 8–12 February*, *1988* (Vol. I, pp. 1–94). Taipei: SMC Publishing.

Bayard, D. T. (1972). Early Thai bronze: Analysis and new dates. *Science*, *176*, 1411–1412.

Bayard, D. T. (1979). The chronology of prehistoric metallurgy in north-east Thailand: *Silabhumi* or *Samrddhabhumi*? In R. B. Smith & W. Watson (Eds.), *Early South East Asia: Essays in archaeology, history and historical geography* (pp. 15–32). New York: Oxford University Press.

Bayard, D. T. (1980). An early indigenous bronze technology in northeast Thailand: Its implications for the prehistory of East Asia. In H. H. E. Loofs-Wissowa (Ed.), *The diffusion of material culture: 28th International Congress of Orientalists, Proceedings of Seminar E, Canberra, January 1971* (pp. 191–214). Asian and Pacific Archaeology Series No. 9. Honolulu: Social Science Research Institute, University of Hawaii at Manoa.

Bayard, D. T. (1981). Temporal distribution and alloy variation in early bronzes from Non Nok Tha. *Current Anthropology*, *22*, 697–699.

Bayard, D. T. (1996–1997). Bones of contention: The Non Nok Tha burials and the chronology and context of early Southeast Asian bronze. In F. D. Bulbeck & N. Barnard (Eds.), *Ancient Chinese and Southeast Asian Bronze Age cultures. The Proceedings of a Conference Held at the Edith and Joy London Foundation Property, Kioloa, NSW, Australia, 8–12 February*, *1988* (Vol. II, pp. 889–940). Taipei: SMC Publishing.

Bayard, D. T., & Charoenwongsa, P. (1983). The development of metallurgy in Southeast Asia: Reply to Loofs-Wissowa. *Journal of Southeast Asian Studies*, *14*(1), 12–17.

Bayard, D. T., & Solheim, W. G. II. (1991). *Archaeological Excavations at Non Nok Tha, Northeast Thailand, 1966–1968*. Unpublished manuscript, Department of Anthropology, University of Otago, Dunedin, New Zealand.

Bennett, A. (1988). Prehistoric copper smelting in central Thailand. In P. Charoenwongsa & B. Bronson (Eds.), *Prehistoric studies: The stone and metal ages in Thailand* (pp. 125–135). Papers in Thai Antiquity 1. Bangkok: Thai Antiquity Working Group.

Bettinger, R. L., & Eerkens, J. (1999). Point typologies, cultural transmission, and the spread of bow-and-arrow technology in the prehistoric Great Basin. *American Antiquity*, *64*(2), 231–242.

Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process*. Chicago: University of Chicago Press.

Bunk, W. G. J., Hauptmann, A., Kölschbach, S., & Woelk, G. (2004). Wind-powered copper smelting technology from the 3rd millennium BC at Feinan/Jordan. In G.-H. Kim, K.-W. Yi, & H.-T. Kang (Eds.), *Messages from the history of metals to the future Metal Age: Proceedings of the 5th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA V), 21–24 April 2002* (pp. 331–338). Korea: Gyeongju.

Chang, N. J. (2004). The personal ornaments. In C. Higham & R. Thosarat (Eds.), *The excavation of Ban Lum Khao* (Vol. 1, pp. 217–230). Bangkok: The Thai Fine Arts Department.

Chernykh, E. N. (1992). *Ancient metallurgy in the USSR: The early Metal Age*. New Studies in Archaeology. Cambridge: Cambridge University Press.

Chernykh, E. N. (2009). Ancient metalurgy in the Eurasian steppes and China: problems of interaction. In J. Mei & Th. Rehren (Eds.), *Metallurgy and civilisation: Eurasia and beyond. Proceedings of the 6th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VI)* (pp. 3–8). London: Archetype Publications.

Chernykh, E. N., Kuz'minykh, S. V., & Orlovskaya, L. B. (2004). Ancient metallurgy in northeast Asia: From the Urals to the Saiano–Altai. In K. M. Linduff (Ed.), *Metallurgy in ancient eastern Eurasia from the Urals to the Yellow River* (Vol. 31, pp. 15–36). Lewiston: Edwin Mellen Press. (Chinese Studies).

Childe, V. G. (1954). The socketed celt in upper Eurasia. *Annual Report of the Institute of Archaeology of the University of London*, *10*, 11–25.

Chiou-Peng, T. (1998). Western Yunnan and its steppe affinities. In V. H. Mair (Ed.), *The Bronze Age and Early Iron Age peoples of eastern central Asia. Volume 1: Archaeology, migration and nomadism, linguistics* (pp. 280–304). Journal of Indo-European Studies Monograph No. 26. Washington: Institute for the Study of Man in collaboration with University of Pennsylvania Museum Publications.

Chiou-Peng, T. (2009). Incipient metallurgy in Yunnan: New data for old debates. In J. Mei & Th. Rehren (Eds.), *Metallurgy and civilisation: Eurasia and beyond. Proceedings of the 6th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VI)* (pp. 79–84). London: Archetype Publications.

Ciarla, R. (1992). The Thai-Italian Lopburi Regional Archaeological Project: Preliminary results. In I. C. Glover (Ed.), *Southeast Asian Archaeology 1990. Proceedings of the Third Conference of the European Association of Southeast Asian Archaeologists* (pp. 111–128). Hull: Centre for South-East Asian Studies, University of Hull.

Ciarla, R. (2007). Rethinking Yuanlongpo: The case for technological links between the Lingnan (PRC) and central Thailand in the Bronze Age. *East and West*, *57*(1–4), 305–328.

Costin, C. L. (1991). Craft specialization: Issues in defining, documenting, and explaining the organization of production. In M. B. Schiffer (Ed.), *Archaeological method and theory, Volume 3* (pp. 1–56). Tucson: University of Arizona Press.

Costin, C. L. (2005) Craft production. In H. D. G. Maschner & C. Chippindale (Eds.), *Handbook of archaeological methods, Volume II* (pp. 1034–1107). New York: Altimira.

Dalton, G. (1977). Aboriginal economics in stateless societies. In T. K. Earle & J. E. Ericson (Eds.), *Exchange systems in prehistory* (pp. 191–211). London: Academic Press.

Davey, C. (2009). The early history of lost-wax casting. In J. Mei & Th. Rehren (Eds.), *Metallurgy and civilisation: Eurasia and beyond. Proceedings of the 6th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VI)* (pp. 147–154). London: Archetype Publications.

Epstein, S. M. (1993). *Cultural choice and technological consequences: Constraint of innovation in the late prehistoric copper smelting industry of Cerro Huaringa, Peru*. Unpublished PhD. Dissertation, Department of Anthropology, University of Pennsylvania, Philadelphia.

Eyre, C. O. (2006). *Prehistoric and proto-historic communities in the eastern upper Chao Phraya River Valley, Thailand: Analysis of site chronology, settlement patterns, and land use*. Unpublished PhD. Dissertation, Department of Anthropology, University of Pennsylvania, Philadelphia.

Fitzgerald-Huber, L. G. (1995). Qijia and Erlitou: The question of contacts with distant cultures. *Early China*, *20*, 17–67.

Fitzgerald-Huber, L. G. (2003). The Qijia culture: Paths east and west. *Bulletin of the Museum of Far Eastern Antiquities*, *75*, 55–78.

Gorsdorf, J., Parzinger, H., & Nagler, A. (2004). ^{14}C dating of the Siberian steppe zone from Bronze Age to Scythian Time. In E. M. Scott, A. Y. Alekseev, & G. Zaitseva (Eds.), *Impact of the environment on human migration in Eurasia* (pp. 83–89). NATO Science Series IV: Earth and Environmental Sciences. Boston: Kluwer Academic Publishers.

Hall, T. D., & Chase-Dunn, C. (1993). The world-systems perspective and archaeology: Forward into the past. *Journal of Archaeological Research*, *1*(2), 121–143.

Hanks, B. K., & Doonan, R. C. P. (2009). From scale to practice: A new agenda for the study of early metallurgy on the Eurasian Steppe. *Journal of World Prehistory*, *22*(4), 329–356.

Hanks, B. K., Epimakhov, A. V., & Renfrew, A. C. (2007). Towards a refined chronology for the Bronze Age of the southern Urals, Russia. *Antiquity*, *81*, 353–367.

Henrich, J. (2001). Cultural transmission and the diffusion of innovations: Adoption dynamics indicate that biased cultural transmission is the predominate force in behavioral change. *American Anthropologist*, *103*(4), 992–1013.

Higham, C. F. W. (1984). The Ban Chiang culture in wider perspective. *Proceedings of the British Academy*, *69*, 229–261.

Higham, C. F. W. (1988). Prehistoric metallurgy in Southeast Asia: Some new information from the excavations of Ban Na Di. In R. Maddin (Ed.), *The beginning of the use of metals and alloys: Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21–26 October 1986* (pp. 130–155). Cambridge: MIT Press.

Higham, C. F. W. (1989). *The archaeology of mainland Southeast Asia: From 10,000 BC to the fall of Angkor*. Cambridge: Cambridge University Press.

Higham, C. F. W. (1996). *The Bronze Age of Southeast Asia*. Cambridge: Cambridge University.

Higham, C. F. W. (1996–1997). The social and chronological contexts of early bronze working in Southeast Asia. In F. D. Bulbeck & N. Barnard (Eds.), *Ancient Chinese and Southeast Asian Bronze Age cultures, Volume II. The Proceedings of a Conference Held at the Edith and Joy London Foundation Property, Kioloa, NSW, Australia, 8–12 February*, *1988* (pp. 821–888). Taipei: SMC Publishing.

Higham, C. F. W. (2002). *Early cultures of mainland Southeast Asia*. Bangkok: River Books.

Higham, C. F. W. (2004). Mainland Southeast Asia from the Neolithic to the Iron Age. In I. Glover & P. Bellwood (Eds.), *Southeast Asia: From prehistory to history* (pp. 41–67). London: RoutledgeCurzon.

Higham, C. F. W. (2006). Crossing national boundaries: Southern China and Southeast Asia in prehistory. In E. A. Bacus, I. C. Glover, & V. C. Pigott (Eds.), *Uncovering Southeast Asia's past: Selected Papers from the 10th International Conference of the European Association of Southeast Asian Archaeologists* (pp. 13–21). Singapore: National University of Singapore Press.

Higham, C. F. W. (2007). Summary and conclusions. In C. F. W. Higham, A. Kijngam , & S. Talbot (Eds.), *The origins of the civilization of Angkor, Volume 2. The Excavation of Noen U-Loke and Non Muang Kao* (pp. 595–609). Bangkok: Thai Fine Arts Department.

Higham, C. F. W. (2008). Recasting Thailand: New discoveries at Ban Non Wat. *Current World Archaeology*, *31*, 38–41.

Higham, C. F. W. (2009). Dating the Bronze Age of Southeast Asia: The Cultural Implications. *Journal of Southern Ethnology and Archaeology*. (in press).

Higham, C. F. W., & Higham, T. (2009). A new chronological framework for prehistoric Southeast Asia, based on a Bayesian model from Ban Non Wat. *Antiquity*, *83*, 125–144.

Higham, C. F. W., & Kijngam, A. (1984). *Prehistoric investigations in northeastern Thailand*. BAR International Series 231. Oxford: British Archaeological Reports.

Higham, C. F. W., & Thosarat, R. (1998). *Prehistoric Thailand: From early settlement to Sukhothai*. Bangkok: River Books.

Higham, C. F. W., & Thosarat, R. (2006). Ban Non Wat: The first three seasons. In E. A. Bacus, I. C. Glover, & V. C. Pigott (Eds.), *Uncovering Southeast Asia's Past: Selected Papers from the 10th International Conference of the European Association of Southeast Asian Archaeologists* (pp. 98–104). Singapore: National University of Singapore Press.

Higham, C. F.W., Higham, T., Ciarla, R., Douka, K., Kijngam, A. & Rispoli, F. (2011). The Origins of the Bronze Age of Southeast Asia. *Journal of World Prehistory, 24*(4), 227–274.

Hosler, D. (1995). *The sounds and colors of power: The sacred metallurgical technology of ancient west Mexico*. Cambridge: MIT Press.

Huyen, P. M. (2004). Northern Vietnam from the Neolithic to the Han Period: Part II: The Metal Age in the north of Vietnam. In I. Glover & P. Bellwood (Eds.), *Southeast Asia: From prehistory to history* (pp. 189–201). New York: RoutledgeCurzon.

Killick, D. (2004). Social constructionist approaches to the study of technology. *World Archaeology*, *36*(4), 571–578.

Kim, J. (2001). Élite strategies and the spread of technological innovation: The spread of iron in the Bronze Age Societies of Denmark and Southern Korea. *Journal of Anthropological Archaeology*, *20*(4), 442–478.

Kohl, P. L. (2007). *The making of Bronze Age Eurasia*. New York: Cambridge World Archaeology, Cambridge University Press.

Kohl, P. L. (2008). Shared social fields: Evolutionary convergence in prehistory and contemporary practice. *American Anthropologist*, *110*(4), 495–506.

Koryakova, L. N., & Epimakhov, A. V. (2007). *The Urals and Western Siberia in the Bronze and Iron Ages* (Cambridge World Archaeology). Cambridge: Cambridge University Press.

Kroeber, A. L. (1963). *Anthropology: Culture patterns and processes*. New York: Harbinger books (selections from Kroeber's *Anthropology* published in 1923, 1948).

Kuhn, S. (2004). Evolutionary perspectives on technology and technological change. *World Archaeology*, *36*(4), 561–570.

Kuz'mina, E. E. (2004). Historical perspectives on the Andronovo and metal use in eastern Asia. In K. M. Linduff (Ed.), *Metallurgy in ancient eastern Eurasia from the Urals to the Yellow River* (Vol. 31, pp. 37–84). Lewiston: Edwin Mellen Press (Chinese Studies).

Kuz'mina, E. E. (2008). *The prehistory of the Silk Road (Encounters with Asia).* Philadelphia: University of Pennsylvania Press.

Lemonnier, P. (1986). The study of material culture today: Toward an anthropology of technical systems. *Journal of Anthropological Archaeology*, *5*, 147–186.

Lemonnier, P. (1992). *Elements for an anthropology of technology*. Anthropological Paper 88. Ann Arbor: Museum of Anthropology, University of Michigan.

Linduff, K. M. (1998). The emergence and demise of bronze-producing cultures outside the central plain of China. In V. H. Mair (Ed.), *The Bronze Age and early Iron Age peoples of eastern central Asia, Vol. 2: Genetics and physical anthropology, metallurgy, textiles, geography and climatology, history, and mythology and ethnology* (pp. 619–644). Journal of Indo-European Studies, Monograph No. 26. Washington: Institute for the Study of Man in collaboration with the University of Pennsylvania Museum Publications.

Linduff, K. M. (2000). Introduction. In K. M. Linduff, H. Rubin, & S. Shuyun (Eds.), *The beginnings of metallurgy in China* (Vol. 11, pp. 1–28). Lewiston: Edwin Mellen Press. (Chinese Studies).

Linduff, K. M. (Ed.). (2004a). *Metallurgy in ancient Eastern Eurasia from the Urals to the Yellow River* (Vol. 31). Lewiston: Edwin Mellen Press (Chinese Studies).

Linduff, K. M. (2004b). Introduction: How far does the Eurasian metallurgical tradition extend? In K. M. Linduff (Ed.), *Metallurgy in ancient eastern Eurasia from the Urals to the Yellow River* (Vol. 31, pp. 1–14). Lewiston: Edwin Mellen Press. (Chinese Studies).

Linduff, K. M., Rubin, H., & Shuyun, S. (Eds.). (2000). *The beginnings of metallurgy in China* (Vol. 11). Lewiston: Edwin Mellen Press. (Chinese Studies).

Linduff, K. M., & Mei, J. (2009). Metallurgy in Ancient Eastern Asia: Retrospect and prospects. *Journal of World Prehistory*, *22*(3), 265–281.

Loofs-Wissowa, H. H. E. (1983a). The development of metallurgy in Southeast Asia: Reply to Bayard, Pisit, and Solheim. *Journal of Southeast Asian Studies*, *14*(1), 26–31.

Loofs-Wissowa, H. H. E. (1983b) The development and spread of metallurgy in Southeast Asia: A review of present evidence. *Journal of Southeast Asian Studies*, *14*(1), 1–11.

Lyman, R. L. (2008). Cultural transmission in North American anthropology and archaeology, ca. 1895–1965. In M. J. O'Brien (Ed.), *Cultural transmission and archaeology: Issues and case studies* (pp. 10–20). Washington: Society for American Archaeology Press.

Mair, V. H. (1998a). Priorities. In V. H. Mair (Ed.), *The Bronze Age and early Iron Age peoples of eastern central Asia. Volume 1: Archaeology, migration and nomadism, linguistics* (pp. 4–41). Journal of Indo-European Studies Monograph No. 26. Washington: Institute for the Study of Man in collaboration with University of Pennsylvania Museum Publications.

Mair, V. H. (Ed.). (1998b). *The Bronze Age and Early Iron Age Peoples of eastern central Asia, Volumes. 1–2*. Journal of Indo-European Studies Monograph 26. Washington: Institute for the Study of Man, in collaboration with the University of Pennsylvania Museum Publications.

Mei, J. (2000). *Copper and bronze metallurgy in late prehistoric Xinjiang: Its cultural context and relationship with neighboring regions*. BAR International Series 865. Oxford: Archaeopress.

Mei, J. (2003). Cultural interaction between China and central Asia during the Bronze Age. *Proceedings of the British Academy*, *121*, 1–39.

Mei, J. (2004). Metallurgy in Bronze Age Xinjiang and its cultural context. In K. M. Linduff (Ed.), *Metallurgy in ancient eastern Eurasia from the Urals to the Yellow River* (Vol. 31, pp. 173–188). Lewiston: Edwin Mellen Press. (Chinese Studies).

Mei, J. (2009). Early metallurgy in China: Some challenging issues in current studies. In J. Mei & Th. Rehren (Eds.), *Metallurgy and civilisation: Eurasia and beyond. Proceedings of the 6th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VI)* (pp. 9–16). London: Archetype Publications.

Mesoudi, A., & O'Brien, M. J. (2008a). The cultural transmission of Great Basin projectile-point technology I: An experimental simulation. *American Antiquity*, *73*(1), 3–28.

Mesoudi, A., & O'Brien, M. J. (2008b). The cultural transmission of Great Basin projectile-point technology II: An agent-based computer simulation. *American Antiquity*, *73*(4), 627–644.

Muhly, J. D. (1988). The beginnings of metallurgy in the Old World. In R. Maddin (Ed.), *The beginning of the use of metals and alloys: Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21–26 October 1986* (pp. 2–20). Cambridge: MIT Press.

Murowchick, R. E. (1988). The development of early bronze metallurgy in Vietnam and Kampuchea: A reexamination of recent work. In R. Maddin (Ed.), *The beginning of the use of metals and alloys: Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21–26 October 1986* (pp. 182–199). Cambridge: MIT Press.

Murowchick, R. E. (1989). *The ancient bronze metallurgy of Yunnan and its environs: Development and implications*. Unpublished PhD. Dissertation, Department of Anthropology, Harvard University, Cambridge.

Nash, S. (n.d.). *Report on the microstructure and chemistry of two metallic artifacts from Ban Mai Chai Monkol and Ban Pong Manao*. Unpublished manuscript, MASCA, University of Pennsylvania, Philadelphia.

Natapintu, S. (1988). Current research on ancient copper-base metallurgy in Thailand. In P. Charoenwongsa & B. Bronson (Eds), *Prehistoric studies: The Stone and Metal Ages in Thailand* (pp. 107–124). Papers in Thai Antiquity 1. Bangkok, Thai Antiquity Working Group.

O'Brien, M. J. (Ed.). (2008). *Cultural transmission and archaeology: Issues and case studies*. Washington: Society for American Archaeology Press.

Onsuwan, C. (2000). *Excavation of Ban Mai Chaimongkol, Nakhon Sawan Province, central Thailand: A study of site stratigraphy, chronology and its implications for the prehistory of central Thailand*. Unpublished M.A. thesis, Department of Anthropology, University of Pennsylvania, Philadelphia.

O'Reilly, D. J. W. (2001). From the Bronze Age to the Iron Age in Thailand: Applying the heterarchical approach. *Asian Perspectives*, *39*(1–2), 1–19.

Pétrequin, P. (1993). North wind, south wind: Neolithic technical choices in the Jura Mountains, 3700–2400 BC. In P. Lemonnier (Ed.), *Technical choices: Transformations in material cultures since the Neolithic* (pp. 36–76). New York: Routledge.

Pietrusewsky, M., & Douglas, M. T. (2002). *Ban Chiang, a prehistoric village site in northeast Thailand I: The human skeletal remains*. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology. (Thai Archaeology Monograph Series).

Pigott, V. C. (1998). Prehistoric copper mining in the context of emerging community craft specialisation in northeast Thailand. In A. B. Knapp, V. C. Pigott, & E. W. Herbert (Eds.), *Social approaches to an industrial past: The archaeology and anthropology of mining* (pp. 205–225). New York: Routledge.

Pigott, V. C. (1999). Reconstructing the copper production process as practised among prehistoric mining/metallurgical communities in the Khao Wong Prachan Valley of central Thailand. In S. M. M. Young, A. M. Pollard, P. Budd, & R. A. Ixer (Eds.), *Metals in antiquity* (pp. 10–21). Oxford: Archaeopress. (BAR International Series No. 792).

Pigott, V. C., & Ciarla, R. (2007). On the origins of metallurgy in prehistoric Southeast Asia: The view from Thailand. In S. La Niece, D. Hook, & P. Craddock (Eds.), *Metals and mines: Studies in archaeometallurgy* (pp. 76–88). London: Archetype Press in association with the British Museum.

Pigott, V. C., & Natapintu, S. (1988). Archaeological investigations into prehistoric copper production: The Thailand Archaeometallurgy Project 1984–1986. In Maddin, R. (Ed.), *The beginning* *of the use of metals and alloys: Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21–26 October 1986* (pp. 156–162). Cambridge: MIT Press.

Pigott, V. C., & Natapintu, S. (1996–1997). Investigating the origins of metal use in prehistoric Thailand. In F. D. Bulbeck and N. Barnard (Eds.), *Ancient Chinese and Southeast Asian Bronze Age cultures, Volume II. The Proceedings of a Conference Held at the Edith and Joy London Foundation Property, Kioloa, NSW, Australia, 8–12 February*, *1988* (pp. 787–808). Taipei: SMC Publishing.

Pigott, V. C., & Weisgerber, G. (1998). Mining archaeology in geological context: The prehistoric copper mining complex at Phu Lon, Nong Khai Province, northeast Thailand. *Der Anschnitt. Beiheft*, *8*, 135–162.

Pigott, V. C., Weiss, A. D., & Natapintu, S. (1997). The archaeology of copper production: Excavations in the Khao Wong Prachan Valley, central Thailand. In R. Ciarla & F., Rispoli, (Eds.), *South-East Asian Archaeology 1992. Proceedings of the Fourth International Conference of the European Association of South-East Asian Archaeologists. Rome, 28th September—4th October 1992* (Vol. 77, pp. 119–157). Rome: Istituto Italiano per L'Africa e L'Oriente. (Serie Orientale Roma).

Pryce, T. O. (2009). *Prehistoric copper production and technological production in the Khao Wong Prachan Valley of central Thailand*. Unpublished dissertation, UCL Institute of Archaeology, University College London, London. Available at http://sites.google.com/site/thomasoliverpryce/.

Pryce, T. O., & Pigott, V. C. (2008). Towards a definition of technological styles in prehistoric copper smelting in the Khao Wong Prachan Valley of central Thailand. In J.-P. Pautreau, A. Coupey, V. Zeitoun, & E. Rambault (Eds.), *Archaeology in Southeast Asia: From* Homo Erectus *to the living traditions, choice of papers from the 11th Euraseaa Conference, Bougon 2006* (pp. 139–150). Chiang-Mai: European Association of Southeast Asian Archaeologists.

Pryce, T. O., Bassiakos Y., Catapotis, M., & Doonan, R. C. P. (2007). 'De Caerimoniae' Technological choices in copper-smelting furnace design at Early Bronze Age Chrysokamino, Crete. *Archaeometry*, *49*(3), 543–557.

Rehren, Th. (2003). Crucibles as reaction vessels in ancient metallurgy. In P. Craddock and J. Lang (Eds.), *Mining and metal production through the ages* (pp. 207–215). London: The British Museum Press.

Roberts, B. W., Thornton, C. P., & Pigott, V. C. (2009). Development of Metallurgy in Eurasia. *Antiquity, 83*(322), 1012–1022.

Rostoker, W., Pigott, V. C., & Dvorak, J. (1989). Direct reduction to copper metal by oxide-sulfide mineral interaction. *Archeomaterials*, *3*, 69–87.

Schiffer, M. B. (Ed.). (2001a). *Anthropological perspectives on technology*. Albuquerque: University of New Mexico Press. (Amerind Foundation New World Series, No. 5).

Schiffer, M. B. (2001b). Toward an anthropology of technology. In M. B. Schiffer (Ed.), *Anthropological perspectives on technology*. (pp. 1–15). Albuquerque: University of New Mexico Press. (Amerind Foundation New World Studies Series No. 5).

Schiffer, M. B. (2004). Studying technological change: A behavioral perspective. *World Archaeology*, *36*(4), 589–585.

Schiffer, M. B. (2005). The devil is in the details: The cascade model of invention processes. *American Antiquity*, *70*(3), 485–502.

Schiffer, M. B. (2008). Transmission processes: A behavioral perspective. In M. J. O'Brien (Ed.), *Cultural transmission and archaeology: Issues and case studies* (pp. 102–111). Washington: Society for American Archaeology.

Selimkhanov, I. R. (1979) The chemical characteristics of some metal finds from Non Nok Tha. In R. B. Smith & W. Watson (Eds.), *Early South East Asia: Essays in archaeology, history and historical geography* (pp. 33–38). New York: Oxford University Press.

Sherratt, A. (2006). The Trans–Eurasian exchange: The prehistory of Chinese relations with the West. In V. H. Mair (Ed.), *Contact and exchange in the ancient world* (pp. 30–61). Honolulu: University of Hawaii Press. (Perspectives on the Global Past).

Shuyun, S., & Rubin, H. (2000a). A study of casting and manufacturing techniques of early copper and bronze artifacts found in Gansu. In K. M. Linduff, H. Rubin, & S. Shuyun (Eds.), *The beginnings of metallurgy in China* (Vol. 11, pp. 175–193). Lewiston: Edwin Mellen Press. (Chinese Studies).

Shuyun, S., & Rubin, H. (2000b). A preliminary study of early Chinese copper and bronze artifacts. In K. M. Linduff, H. Rubin, & S. Shuyun (Eds.), *The beginnings of metallurgy in China* (Vol. 11, pp. 129–151). Lewiston: Edwin Mellen Press. (Chinese Studies).

Smith, C. S. (1973). Bronze technology in the East: A metallurgical study of early Thai bronzes with some speculations on the cultural transmissions of technology. In M. Teich & R. Young (Eds.), *Changing perspectives in the history of science: Essays in honor of Joseph Needham* (pp. 21–32). London: Heinemann.

Solheim, W. G., II. (1968). Early bronze in northeastern Thailand. *Current Anthropology*, *9*, 59–62.

Solheim, W. G., II. (1983). The development of metallurgy in Southeast Asia: Another reply to Loofs-Wissowa. *Journal of Southeast Asian Studies*, *14*(1), 18–25.

Spriggs, M. J. T. (1996–1997). The dating of Non Nok Tha and the 'Gakushuin Factor'. In F. D. Bulbeck & N. Barnard (Eds.), *Ancient Chinese and Southeast Asian Bronze Age cultures, Volume II. The Proceedings of a Conference Held at the Edith and Joy London Foundation Property, Kioloa, NSW, Australia, 8–12 February*, *1988* (pp. 941–948). Taipei: SMC Publishing.

Stech Wheeler, T., & Maddin, R. (1976). The techniques of the early Thai metalsmith. *Expedition*, *18*(4), 38–47.

Stech, T., & Maddin, R. (1988). Reflections on early metallurgy in Southeast Asia. In R. Maddin, (Ed.), *The beginning of the use of metals and alloys. Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21–26 October 1986* (pp. 163–174). Cambridge: MIT Press.

Stein, G. J. (1999). *Rethinking world-systems: Diasporas, colonies, and interaction in Uruk Mesopotamia*. Tucson, AZ: University of Arizona Press.

Thorp, R. L. (2006). *China in the early Bronze Age: Shang Civilization Encounters with Asia*. Philadelphia: University of Pennsylvania Press.

Tylecote, R. F. (1996–1997). Recent observations on early metallurgy in China—a note. In F. D. Bulbeck & N. Barnard (Eds.), *Ancient Chinese and Southeast Asian Bronze Age cultures, Volume II. The Proceedings of a Conference Held at the Edith and Joy London Foundation Property, Kioloa, NSW, Australia, 8–12 February*, *1988* (pp. 723–730). Taipei: SMC Publishing.

Van Pool, C. S. (2008). Agents and cultural transmission. In M. J. O'Brien (Ed.), *Cultural transmission and archaeology: Issues and case studies* (pp. 190–200). Washington, D. C.: Society for American Archaeology.

Vernon, W. W. (1988). The crucible in copper-bronze production at prehistoric Phu Lon, northeast Thailand: Analyses and interpretation. *Paper read at the Conference on Ancient Chinese and Southeast Asian Bronze Age cultures, Kioloa, NSW, Australia.*

Vernon, W. W. (1996–1997). The crucible in copper-bronze production at prehistoric Phu Lon, northeast Thailand: Analyses and interpretation. In F. D. Bulbeck & N. Barnard (Eds.), *Ancient Chinese and Southeast Asian Bronze Age cultures, Volume II. The Proceedings of a Conference Held at the Edith and Joy London Foundation Property, Kioloa, NSW, Australia, 8–12 February*, *1988* (pp. 809–820). Taipei: SMC Publishing.

Vernon, W. W. (1997). Chronological variation in crucible technology at Ban Chiang: A preliminary assessment. *Bulletin of the Indo-Pacific Prehistory Association*, *16*, 107–110.

von Falkenhausen, L. (2006). The external connections of Sanxingdui. *Journal of East Asian Archaeology*, *5*(1–4), 191–245.

Watson, W. (1971). *Cultural frontiers in ancient East Asia*. Edinburgh: Edinburgh University Press.

Watson, W. (1985). An interpretation of opposites? Pre-Han bronze metallurgy in west China. *Proceedings of the British Academy*, *70*, 327–358.

Watson, W. (1992). Pre-Han communication from west China to Thailand. In I. C. Glover, P. Suchitta, & J. Villiers (Eds.), *Early metallurgy, trade and urban centres in Thailand and Southeast Asia* (pp. 175–180). Bangkok: White Lotus.

White, J. C. (1982). *Ban Chiang: Discovery of a lost Bronze Age*. Philadelphia: The University Museum, University of Pennsylvania and the Smithsonian Institution Traveling Exhibition Service.

White, J. C. (1986). *A revision of the chronology of Ban Chiang and its implications for the prehistory of northeast Thailand*. Unpublished PhD. Dissertation, Department of Anthropology, University of Pennsylvania, Philadelphia.

White, J. C. (1988). Early East Asian metallurgy: The southern tradition. In R. Maddin (Ed.), *The beginning of the use of metals and alloys: Papers from the Second International Conference on the Beginning of the Use of Metals and Alloys, Zhengzhou, China, 21–26 October 1986* (pp. 175–181). Cambridge, MA: MIT Press.

White, J. C. (1995). Incorporating heterarchy into theory on socio-political development: The case from Southeast Asia. In R. M. Ehrenreich, C. L. Crumley, & J. E. Levy (Eds.), *Heterarchy and the analysis of complex societies* (pp. 101–123). Archeological Papers of the American Anthropological Association No. 6. Arlington: American Anthropological Association.

White, J. C. (1997). A brief note on new dates for the Ban Chiang cultural tradition. *Bulletin of the Indo-Pacific Prehistory Association*, *16*, 103–106.

White, J. C. (2000). Review of 'Prehistoric Thailand: From early settlement to Sukhothai' by Charles Higham and Rachanie Thorsarat. *Journal of Asian Studies*, *59*(4), 1093–1094.

White, J. C. (2008). Dating early bronze at Ban Chiang, Thailand. In J.-P. Pautreau, A.-S. Coupey, V. Zeitoun, & E. Rambault (Eds.), *Archaeology in Southeast Asia: From* Homo Erectus *to the living traditions, choice of Papers from the 11th EurASEAA Conference, Bougon 2006* (pp. 91–104). Chiang-Mai: European Association of Southeast Asian Archaeologists.

White, J. C., & Pigott, V. C. (1996). From community craft to regional specialization: Intensification of copper production in prestate Thailand. In B. Wailes (Ed.), *Craft specialization and social evolution: In memory of V. Gordon Childe* (pp. 151–175). University Museum Monograph 93. Philadelphia: The University Museum of Archaeology and Anthropology, University of Pennsylvania.

White, J, C., & Hamilton, E. G. (2009). The Transmission of Early Bronze Technology to Thailand: New Perspectives. *Journal of World Prehistory*, *22*(4), 357–397.

White, J. C., Vernon, W. W., Fleming, S. J., Glanzman, W. D., Hancock, R. G. V., & Pelcin, A. (1991). Preliminary cultural implications from initial studies of the ceramic technology at Ban Chiang. *Bulletin of the Indo-Pacific Prehistory Association*, *11*, 188–203.

Yan, W. (2000). A discussion of the Chalcolithic Age in China. In K. M. Linduff, H. Rubin, & S. Shuyun (Eds.), *The beginnings of metallurgy in China* (Vol. 11, pp. 100–115). Lewiston: Edwin Mellen Press. (Chinese Studies).

Yang, M. (2002). Erlitou bronze plaques inlaid with turquoise (in Chinese). *Miho Museum Kenky*ū *kiy*, *3*, 27–77.

Zhou, W., Dong, Y., Wan, Q., & Wang, C. (2009). New research on lost-wax casting in ancient China. In J. Mei & Th. Rehren (Eds.) *Metallurgy and civilisation: Eurasia and beyond. Proceedings of the 6th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VI)* (pp. 73–78). London: Archetype Publications.