From Metallurgy to Bronze Age Civilizations: The Synthetic Theory

NISSIM AMZALLAG

Abstract

During the past few decades, evidence for the ancient smelting of copper has been discovered in areas isolated from one another. In most of them, the beginning of metallurgy had no substantial social and cultural consequences. Accordingly, the diffusionist theory (assuming the existence of a single homeland for metallurgy and its central importance in cultural development) has been replaced by a localizationist theory, in which the emergence of metallurgy is simply a continuation of the working of native copper. But neither of these theories is able either to correlate similarities observed among disparate Bronze Age civilizations or to explain the status of the smelter as civilizing hero in ancient mythologies. The problem, I argue, arises because previous scholars did not distinguish properly between two modes of copper production: crucible metallurgy and furnace smelting. According to the localizationist theory, crucible metallurgy appears as a spontaneous extension of the melting of native copper but does not result in any substantial cultural change, whereas the general principles of a diffusionist theory would regard the emergence of furnace metallurgy as a unique event that spread rapidly and spurred on vast cultural changes (if diffusionists had ever actually understood the difference between the two production methods). I propose instead a synthetic theory in which the spread of furnace metallurgy—which was fundamentally different from crucible metallurgy and depended on complex technical knowledge—from the southern Levant generated a wide network linking Bronze Age societies. This has important implications for our understanding of the international network of exchanges in technology, artifacts, and ideas during the Bronze Age.*

INTRODUCTION

Scholarship in the first half of the 20th century held that the emergence of copper metallurgy was a central factor in the development of the earliest civilizations. It was assumed that metal tools improved agriculture, which, in turn, led to a rapid population increase and the emergence of elites who controlled copper production and trade. At the same time, the increasing demand for metallurgical artifacts was regarded as a driving force that encouraged inventiveness and technical progress among the smiths. This scenario was mainly based on archaeological investigations in Mesopotamia and Egypt, where copper artifacts were found from the earliest stages of the development of complex society.[1] Consequently, the Near East came to be regarded as the most ancient homeland of metallurgy, whence radiated both metallurgy and a civilizing impetus.[2]

During the second half of the 20th century, however, scholars identified many other homelands of metallurgy (the Balkans, the Iranian plateau, Spain, South America, Thailand).[3] Moreover, the autonomous development of copper metallurgy discovered in the Aegean refuted the idea of local diffusion from neighboring areas (the Balkans or the Near East).[4] For these reasons, the diffusionist theory was replaced by a localizationist theory postulating a polyphyletic origin of metallurgy.

The diffusionist theory associated metallurgy with the emergence of social complexity, which is considered the earliest stage in the development of civilization. But this linkage is somewhat spurious: on the Iberian peninsula, for example, metallurgy remained—for at least a millennium—a secondary activity (mainly producing ornaments) without substantial cultural and social influence.[5] Likewise in Thailand, where metallurgy focused on the production of utilitarian artifacts from the earliest stages of its development, the prehistoric society did not evolve toward a centralization/concentration of power.[6]

Nor is the mastery of metallurgy directly related to any civilizing advancement, as assumed by the diffu-

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[1] Wenke 1991; Rothman 2004.

[2] Wailes 1996, 5.

[3] Solheim 1968; Patterson 1971; Renfrew 1973; Bayard 1981; Jovanovic 1985; Glumac and Todd 1991.

[4] Renfrew 1972.

[5] Rovira 2002.

[6] Bayard 1980; White and Pigott 1996.

sionist theory. The Nahal Mishmar hoard, a unique collection of southern Levantine prestige artifacts from the early fourth millennium B.C.E., for example, is characterized by a complex method of manufacture (the lost-wax casting technique) and a surprising knowledge and practical application of alloying processes.[7] Nonetheless, this outstanding technical advancement is unrelated to any social hierarchy and concentration of power in the southern Levant.[8] Moreover, during the third millennium B.C.E., no significant differences have been noted between techniques used by peoples from Central Asia (e.g., the Andronovo culture, with a low level of social organization) and by their neighbors living in the city-states on the Iranian plateau.[9]

In the localizationist scheme, metallurgy becomes only one of a series of factors (e.g., human migration, ecological change, introduction of new species, new discoveries) contributing to the emergence of highly organized societies.[10] Theoretically, this process is expected to generate a great diversity among the Bronze Age societies, but their comparison points on unsuspected similarities remain unexplained in a localizationist context.

The diffusionist and localizationist theories integrate separate parts of the real situation. From an epistemological view, this cognitive dissonance suggests that these theories suffer a common flaw in their basic statements. At the earliest stages of metallurgy, crucibles and furnaces are used to produce copper, but these processes are not delineated in the diffusionist or localizationist theories because scholars frequently do not devote enough attention to the way the copper is produced. Taking note of the differences between crucible and furnace processes of copper smelting, however, enables us to integrate these contradicting views into a common framework, a synthetic theory that has broad implications for understanding technology, trade, and culture in the Bronze Age.

CRUCIBLE SMELTING

Melting (liquefaction by heating) of native copper in crucibles for its casting was known before heat conversion of ore in the metal (smelting). But in the earliest stages, smelting was frequently done in crucibles. This encourages us to investigate the link between melting and smelting.

From Melting to Smelting

The smelting of copper in a crucible has been noted in many areas of Asia, Europe, and South and Central America between the fifth and the second millennia B.C.E. (table 1). Such a distribution suggests that this mode of copper smelting appeared independently in at least seven areas: the Iranian plateau, the northern Euphrates, the Balkans, Central Europe, the Iberian peninsula, Thailand, and South America. Accordingly, the emergence of crucible smelting of copper should not be considered an exceptional event.

An analysis of information from the Anarak region (in the Iranian plateau) suggests a sequence for the development of crucible smelting. In this area, malachite was mined from the ninth millennium B.C.E. as a semiprecious stone and/or pigment, and native copper was worked from the seventh millennium B.C.E., first by cold hammering, a technique later replaced by heat hammering and annealing. From the early fifth millennium B.C.E., copper (probably of native origin) was melted and then cast in open/bivalve molds.[11] At Tepe Ghabristan, in addition to casting molds, crushed malachite has been found near heavily slagged crucibles, confirming that copper ore was indeed smelted.[12] The same temporal sequence of events (cold and heat hammering, annealing, and casting of native copper) preceded the emergence of crucible smelting of copper in the northern Euphrates area.[13] It seems, therefore, that crucible smelting was discovered in the context of extraction of native copper from its mineral gangue

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[7] Bar-Adon 1980.

[8] Gilead 1994; Fletcher 2008. This finding was considered so abnormal within the classical perspective of development of civilizations that the artifacts were for a long time considered to originate from Mesopotamia. The Nahal Mishmar cave was therefore interpreted as a repository or hiding place for the trade between Mesopotamia and Egypt (Gates 1992). But recent analyses have attested the local origin of these objects (Goren 2008).

[9] Kohl (2007, 248) noticed that "[t]he more egalitarian 'barbarians' on the steppes were not technologically deficient in terms of their abilities to mine and work metals essential to their way of life; if anything, they were relatively advanced in this respect compared with their 'civilized' neighbors, to the south."

[10] Ruiz (1993, 56) even concluded that "explanations that give great causal weight to metallurgy in the dynamics of copper-bronze age change in Iberia need to be replaced by alternatives that give metal its appropriate value. It is difficult to suppose that the formation and consolidation of an elite could be based on a small-scale industry that was not essential for subsistence and that depended on raw materials whose availability could not be easily restricted. The causes of social differentiation must be sought in the intensification of other activities."

[11] Pigott 1999a, 73; Hauptmann 2007, 256–57.

[12] Majidzadeh 1979; Pigott 1999a, 77.

[13] Muhly 1989; Pigott 1996; Özbal et al. 2000; Yener 2000; Hauptmann 2007, 158.

Table 1. Sites of Crucible Smelting of Copper.

Earliest Occurrence	Geographical Area	Location	References
Fifth millennium B.C.E.	Iranian plateau	Tepe Ghabristan	Majidzadeh 1979; Pigott 1999a, 77
		Tal-i-Iblis	Smith 1967; Caldwell 1968
	northern Euphrates	Norsuntepe	Hauptmann 2007, 158
		Aslantepe	Özbal et al. 2000
		Ergani Maden	Özbal et al. 2000
	Balkans and Greece	Gumelnitsa	Ryndina et al. 1999; Gale et al. 2003
		Sitagroi	McGeehan-Liritzis and Gale 1988
		Anza	Gale 1991
	Central Europe	Inn Valley	Krause 1989; Höppner et al. 2005
	Iberian peninsula	Cerro Virtud	Ruiz-Taboada and Montero-Ruiz 1999
Fourth millennium B.C.E.	Iranian plateau	Tepe Yahya	Heskel and Lamberg-Karlovsky 1980
		Seistan	Kennoyer and Miller 1999, 116, 121–22
		Baluchistan	Allchin and Hammond 1978, 89–90
		Mehrgarh	Jarrige 1984
	Cyclades	Kephala (Kea)	Coleman 1977
	Central Europe	Constance Lake	Strahm 1994
	Thailand	Non Nok Tha	Bayard 1980; White and Pigott 1996
		Khao Phu Kha	Bennett 1989
Third millennium B.C.E.	Cambodia	Sekon	Levy 1943
	Iberian peninsula	El Argar	Ruiz 1993
Second millennium B.C.E.	South America	Andes	Donnan 1973; Hosler 1988; Shimada and Merkel 1991

by melting.[14] This assumption is supported by the following considerations:

1. Crucible smelting appears in areas of exploitation of native copper.[15]
2. Native copper, when mined, is embedded in a mineral gangue rich in copper ore. Therefore, the attempt to separate the native copper from its gangue is a sufficient condition for the discovery of smelting.
3. Field experiments have confirmed that smelting in a crucible quite easily may occur for copper ore of a very high grade and/or specific nature.[16]
4. No difference in size and shape is observed between the crucibles used for melting native copper and those later used for the smelting of copper ore, so we can infer that the smelting of copper ore frequently interfered with the melting of native copper in crucible metallurgy.[17]
5. Copper ore was never smelted in North America, though native copper was intensively exploited for a long time.[18] Native copper was heat hammered at a temperature very close to the copper melting point, but native copper was neither melted nor smelted. Here again, the purification of native copper through melting seems to be a crucial stage in the emergence of crucible smelting.

Cosmelting Versus Smelting Processes

Crucible smelting is considered the earliest mode of copper production. Its replacement by furnace smelting everywhere (except in pre-Columbian metallurgy) is justified by the improvements introduced. Large ceramic bowls were used as reactors (the so-called bowl furnace) from the earliest stages of furnace metallurgy (fifth millennium B.C.E.).[19] These bowls, identified as large crucibles, were generally thought to represent the intermediary stage between crucible and pit furnace smelting. Accordingly, the size of the reactor has been judged to be the most important factor governing the transition from crucible to furnace. However, if the difference between crucible and furnace is as simple as that, it is difficult to understand why such a spontaneous development took such a long time. In Thailand and on the Iberian peninsula, the replacement of crucibles by furnaces occurred about 1,500 years after the discovery of crucible smelting,[20] and it never occurred in pre-Columbian metallurgy, despite the high degree of technical achievement of the metal artifacts produced and the extensive knowledge of Amerindian smiths in metal alloying.[21]

Apparently, then, the transition from crucible to furnace is not simply a question of the size of the reactor. Some authors have argued that the crucible, despite its very low yield of copper production, may have been preferred by smelters.[22] But this claim cannot explain why furnace smelting, as soon as it came into being, immediately replaced crucible smelting.[23]

If the bowl furnace is no more than an enlarged crucible, we would expect to find a gradual evolution in shape and size from crucible to bowl furnace. But this is not the case. Except for a few instances, the diameter of smelting crucibles does not exceed 15 cm (and it is frequently smaller than 10 cm), while the diameter of bowl furnaces is never smaller than 30 cm. This difference suggests that bowl furnaces are not enlarged crucibles. Apparently, some physical factor is preventing the increase in size of a crucible but not of a furnace.

Large crucibles (20 cm diam., 15 cm depth) have been discovered in Thailand.[24] But this singularity may

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[14] Craddock 1995.

[15] The first deposits of copper ore exploited in Iran (Veshnoveh, Anarak) contain large amounts of native copper (Pigott 1999a, 77). This is also true for South American metallurgy (Patterson 1971).

[16] Lechtman and Klein 1999; Pigott 1999a.

[17] See Patterson (1971) and Moesta (1986) for South American pre-Columbian metallurgy. Also, in the southeast Iberian peninsula (the El Argar region), the discovery of molds and crucibles with remains of ore reduction suggests a lack of specialization between crucible smelting and melting processes (Ruiz 1993).

[18] According to Wertime (1973), ca. 5,000 tons of native copper were extracted from mines in the Lake Superior area from the third millennium B.C.E. to the time of the European conquest. Native copper was also mined at many other areas in North America (Levine 2007), and it was traded in a wide network of exchange (Cooper et al. 2008).

[19] Tylecote 1987, 108, fig. 4; Golden et al. 2001. During the Early Bronze Age, the smelting of copper ore was sometimes performed in a so-called bowl furnace. This type of reactor has been regarded as a transition stage between the use of a crucible smelting process and that of a "true" pit furnace.

[20] Bayard 1980; Rovira 2002.

[21] Hosler 1988. Patterson (1971, 316) found that "[t]here is no evidence of slagging furnaces, slags, deep mines or cultural factors associated with a sulfide smelting era to indicate sulfide smelting. All chemical compositions of grave-associated Mesoamerican and South American metal artifacts can be understood on the basis of native metals and metals smelted by the reduction of oxidized ores."

[22] Hauptmann (2007, 219) attempted to justify this singularity as a choice of the smelters: "If one considers practical and technical factors, the utilization of crucibles becomes quite logical. It is much easier to keep the valuable raw material, ore or metal in a small container under close control during the smelting process than in an (even very small) furnace. In particular, the management of the firing process is much easier to handle using this method, not only for the control of the temperature but also the redox conditions."

[23] Pigott 1999a; Stech 1999; Krause 2002; Rovira 2002.

[24] Bennett 1989.

be related to another outstanding feature of Thai prehistoric metallurgy: the use of chimneys that induce air convection and limit heat loss from the crucible area.[25] This anomaly suggests that the temperature within the reactor is the limiting factor for the increase in size of the crucible.[26] This limitation is relevant only if the crucible is heated from outside. It points to a fundamental difference between the crucible and furnace smelting, namely that a furnace is filled with a mixture of charcoal and ore (inside heating), while a crucible is not (outside heating).[27]

This singularity of crucible smelting may be dismissed because charcoal is not only the source of heat for the smelting process. Burning charcoal, when mixed with copper ore, is also the source of carbon monoxide, the reducing agent for copper smelting. But charcoal is not the single potential source of reducing agents for smelting. Copper sulfide may be used too. Under high temperatures (ca. 1200°C), the sulfur-rich atmosphere generated by the supply of about 20% of sulfide ore is able to extract the smelt of copper from oxide ore, a process called cosmelting.[28] Some observations suggest that sulfide ore served as a reducing agent in crucible smelting:

1. When used as a reducing agent, charcoal should be mixed with oxide ore. In this case, except for copper ore of very high grade, the small volume of a crucible does not allow the smelting of more than a few grams of copper. It is difficult to believe that the prehistoric smelters invested so great an effort for such a small quantity. The cosmelting process, in contrast, enables one to fill most of the crucible with copper oxide, thereby improving the yield.
2. In the Balkans, copper artifacts produced by crucible smelting show high sulfide content and inclusions of sulfide ore partially smelted (matte).[29]
3. In Thailand, matte is also identified in refractories from crucible metallurgy.[30] But in this case, crushed matte has also been found mixed with crushed ore.[31] This suggests that the prehistoric Thai smelters intentionally used the matte as a reducing agent for the cosmelting process.
4. Copper produced by crucible smelting frequently included arsenic, an element generally present in sulfide but not in oxide ores.[32]

It has been suggested on the basis of this information that sulfide ore may have been used as an exclusive source of copper in crucible smelting. But this is not likely. To become the exclusive source of copper, the sulfide ore should be oxidized first, as follows: the sulfide ore is mixed with charcoal and iron/manganese additives. This mixture is heated at a temperature that increases slowly but does not exceed 800°C, initially to dehydrate the ore, then to ignite the sulfurs and remove them prior to the oxidation of the copper salts. It is only after this process that the roasted ore may be smelted. But the required addition of silicates and other additives, in order to retain iron and manganese in the slags, prevents smelting it in a crucible. Furthermore, the roasting process clearly approximates furnace metallurgy both by the mixing of ore and charcoal and by the use of iron/manganese additives. This is why we may assume that the traces of sulfide ore in copper and refractories indicate a cosmelting process in the crucible.

These general considerations about crucible smelting explain why crucible metallurgy always remained a very limited activity, generally coexisting with the use of native copper. Beyond the limited yield, the reduced volume of the crucible prevented the addition of fluxes, so that successful smelting always depended on the supply of high-grade oxide ore. In these conditions, crucible metallurgy would cease to exist as soon as the grade of the ore diminished.

Identification of crucible smelting as a cosmelting process clearly separates it from furnace smelting (fig. 1). In no way should furnace smelting (mixed ore and

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[25] Pigott 1999b.

[26] Another type of large crucible apparently in use for smelting has been reconstructed from findings from southeast Spain (Ruiz 1993; Rovira 2002). This crucible looks like a plate 30 cm in diameter and ca. 5 cm in depth. This singular shape may be understood, again, as a compromise between the attempt to increase the volume of copper ore smelted and the maintenance of a high temperature by maximizing the contact surface between the source of heat and the crucible. These reactors are also characterized by a thin ceramic wall (<1 cm), enabling maximum heat transfer from the (external) fire to the ore.

[27] This fundamental difference between crucible and furnace has been dismissed because charcoal fragments have been identified in slags from bowl furnaces (Hauptmann 2007, 224). Since bowl furnaces and crucibles were considered to be homolog, the finding of charcoal within bowl furnaces has suggested that it was also introduced within crucibles.

[28] Rostoker et al. 1989; Rostoker and Dvorak 1991; Lechtman and Klein 1999.

[29] Ryndina et al. 1999.

[30] "Refractory" is used in archaeometallurgy as a general term designating crucible, furnace, and tuyère fragments, slag, and matte, all of them having in common an exposure to similar physicochemical conditions (reducing atmosphere and high temperature).

[31] Pigott 1999b.

[32] A preferential mining of copper ore rich in arsenic is observed in the Iranian plateau (region of Anarak, Seistan, and Veshnoveh) during the phase of crucible metallurgy (Pigott 1999a, 73–7).

Characteristics		Crucible Smelting	Furnace Smelting		
			Pit Furnace	Bowl Furnace	Continuous Furnace
Reactor	diam. (cm)	8–20	25–40	30–45	40–60
	depth (cm)	6–15	40	15–30	50–70
	wall thickness (cm)	0.5–2	–	2.5–5	5–10
	porosity	low	–	high	high (external envelope)
Source of heat		around the reactor	within the reactor		
Type of fuel		wood/charcoal	charcoal		
Tuyère/blowpipe connected to the reactor		no	yes		
Reducing agent		mineral (sulfide ore)	organic (CO) (sulfide ore may be added)		
Required quality of ore		high grade	high/moderate grade		moderate/low grade
Type of ore		oxide ore mixed with sulfide ore (reducing agent)	oxide ore (with eventually up to 20% sulfide ore) roasted sulfide ore		
Addition of fluxes		no	iron/manganese/silicates		
Yield (metallic copper)		15–30 g	50–500 g	50–500 g	unlimited

Fig. 1. Comparison of crucible and furnace smelting processes.

charcoal) be considered a spontaneous extension of crucible smelting, a process developed in a context of the purification of native copper. It is therefore important to elucidate the circumstances surrounding the emergence of furnace metallurgy.

THE EARLIEST FURNACE SMELTING

The smelting of copper is attested in the southern Levant (Negev, Aravah, and Sinai) from the fifth millennium B.C.E., but curiously, this metallurgy arises in a region totally devoid of native copper. For this reason, the emergence of metallurgy cannot derive from the purification of native copper from its gangue by being melted in a crucible. To address this peculiarity, it should be noted that copper smelting was not considered a local development in the southern Levant. It was supposedly introduced by northern seminomadic people (Caucasians and/or Anatolians) who brought about transformations in the way of life, habitat, and burial practices for the indigenous population.[33] But this hypothesis contradicts the archaeological data because a continuous evolution in ceramic shape and technology is evident between the Late Neolithic and Chalcolithic phases in southern Canaan.[34] Further-

[33] This theory was first suggested by Ferembach 1959; de Vaux 1966; Mellaart 1966.

[34] Gilead 1990; Merkel and Rothenberg 1999.

more, there is no evidence of the emergence of a new population in this area during the Early Chalcolithic period.[35] Accordingly, the development of copper metallurgy should be considered indigenous to the southern Levant.

Also noteworthy in southern Levantine metallurgy is the occurrence of furnaces from its earliest stages (Timna, fifth millennium B.C.E.).[36] Many scholars have taken exception to this point and have argued that furnace technology was a process much too advanced for this period.[37] Though this tenet fits the classical opinion that assumes a gradual evolution from crucible to furnace smelting, it is challenged by the following observations:

1. The earliest furnace unearthed at Timna (site F2) is extremely archaic in its size and shape. Similar furnaces are not encountered after the Chalcolithic period.
2. Slags from this earliest furnace are characterized by a high content of copper, pointing to an incomplete smelting process. This confirms their ancient origin.
3. Chalcolithic furnaces also have been identified at Beer Sheba (Abu Matar, ca. 4200 B.C.E.).[38] Analysis of their slags reveals a control of the smelting process more advanced than in Timna. This suggests that the earliest furnace from Timna is even older than 4200 B.C.E.

A comparative analysis of chemical composition and structure of slags from southern Araba (Timna and Yotvata)[39] enables the identification of three successive development phases in southern Levantine furnace metallurgy.

Phase 1: High-Viscosity Smelting

The most ancient slags discovered both at Timna and Yotvata are extremely heterogeneous, including many copper prills, veinlets, and dendrites. They are characterized by a dark red shade due to various iron oxides that were used as fluxing agents and the presence of about 10% unsmelted cuprite (Cu_2O).[40] Analysis of the mineral structure of the silicate matrix indicates that it maintains its high viscosity throughout the smelting process. This explains why the smelted copper remained trapped in slags. At this first stage, slags were crushed and the largest copper prills were manually extracted.

Phase 2: Low-Viscosity Smelting

Slags produced later in the same sites are more homogeneous. Their mineral structure reveals a transition toward a low-viscosity stage during the smelting process. Their low copper content indicates that most of the reduced metal was released.[41] The amount of copper oxide was also reduced in comparison with slags belonging to the high-viscosity smelting process. These changes indicate that the smelting process was improved, probably through the use of furnaces reaching a higher temperature and maintaining a more reducing atmosphere. At this stage of development, a copper ingot was generated at the bottom of the furnace, while small copper prills remained trapped in slags.

Phase 3: True-Smelting Process

A new type of slag containing a very low level of copper (<1%) characterizes smelting in the Late Chalcolithic period. This suggests the occurrence of a fluid-phase transition of the mineral matrix during the smelting process, accompanied by manganese-, magnesium-, and calcium-enrichment of slags. This change argues for the use of new fluxes.[42]

This sequence reveals a progressive improvement of the furnace smelting process toward the total liquefaction of the mineral matrix and the complete separation of metal copper and the slags. Other innovations are attested during the course of the Chalcolithic period in the southern Levant. At Beer Sheba, copper oxide ore was mixed with a small fraction of sulfide ore of local origin.[43] This sulfide ore intentionally introduced in the furnace acted as another kind of reducing agent. Arsenic-copper alloy was also intentionally produced through the addition of arsenical sulfide ore imported from mining areas far from Canaan.[44]

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[35] Tangri et al. 1993; Agelarakis et al. 1998.

[36] See Rothenberg and Glass 1992; Rothenberg and Merkel 1995; Rothenberg 1999. This dating is based on typical Chalcolithic flint axes and the radiocarbon dating (4460–4240 B.C.E.) of an ash sample from a habitation near the furnace (Rothenberg and Merkel 1998).

[37] Craddock 2001. The earliest furnaces discovered at Timna have been, therefore, related to the Bronze Age. The main arguments for and against the Chalcolithic dating of the Timna furnace are summarized by Rothenberg (2002) and Hauptmann (2007, 148), respectively.

[38] Shugar 2000. The analysis of slags from the inner part of the bowl furnace from Abu Matar has indeed revealed the presence of charcoal ash (Hauptmann 2007, 224).

[39] Rothenberg and Merkel 1995, 1998; Rothenberg et al. 2004.

[40] Rothenberg et al. 2004; Hauptmann 2007, 159.

[41] Golden et al. 2001; Rothenberg et al. 2004.

[42] Rothenberg et al. 2004; Hauptmann 2007, 160.

[43] Shugar 2000, 194–95.

[44] Shugar 2000, 197–228.

Copper ore was smelted in bowl furnaces at Abu Matar, but crucibles were also used for remelting, purification, and casting the copper smelted in furnaces.[45] Technical innovations are also observed in the alloying processes and artifact production (complex technique of lost-wax casting). From the early fourth millennium B.C.E., an extensive smelting of copper is seen in Penan (Feynan), where copper production is separated into specialized stages (ore preparation, smelting, copper purification, and ingot production).[46]

These observations reveal that southern Levantine metallurgy differs from the others in the manner of its emergence, the process of smelting, its technical achievements, and its rapid evolution toward a "protoindustrial" process of production, purification, and alloying of copper.

THE DIFFUSION OF FURNACE METALLURGY

The most ancient evidence of furnace smelting is recorded in an area devoid of native copper. But what about the presence of furnace metallurgy in mining areas where crucible smelting was already practiced? Did furnace metallurgy emerge spontaneously, or was it introduced from outside? To answer these questions, it may be useful to follow the chronology of the emergence of furnace metallurgy.

Fifth Millennium B.C.E.

Outside of the southern Levant, furnace smelting is fairly common in the late fifth millennium B.C.E. in the northern Euphrates area, a region where copper was already produced by crucible smelting. Many furnaces have been identified around Degirmentepe, for example, where their first appearance corresponds to the seventh stratum of excavation (ca. 4200 B.C.E.). This stratum is characterized by sudden and extensive metallurgical activity (identified by the remains of copper ore, abundant slags, crucibles, and smelting tools).[47] From an examination of the spatial distribution of the findings, it seems that the production process was divided into specialized stages. Degirmentepe, therefore, may be considered the first site of a copper protoindustry in the upper Euphrates.[48]

Progressive improvement in the smelting process is not clear in sites of furnace smelting from this area.[49] It remains difficult to explain this exception by the preexistence of crucible smelting here; the improvement of furnace metallurgy is intimately related to the use of specific fluxes, while a knowledge of fluxes is not required in crucible smelting (see fig. 1). It seems, therefore, that furnace metallurgy is not a local development in the northern Euphrates but had been introduced from outside at a later stage.

Similarities have been noted between Degirmentepe and the southern Levant in the use of hearth-draft furnaces and of iron oxides as fluxing agents.[50] Furthermore, the finding at Beer Sheba of arsenical sulfide ore of probable northern Euphrates origin confirms a link between this area and the southern Levant during the late fifth millennium B.C.E.[51]

Many stamp seals have been found at Degirmentepe. Their extensive use in sealing jars, reed baskets, and leather sacks,[52] together with the relatively rare findings of molds in this site, suggests that most of the copper produced was not for local use. Rather, it was sent far away for the production of copper artifacts.

Stamp seals and ware from Degirmentepe display strong affinities with contemporary artifacts found in the Amuq Valley (phase F).[53] This finding is especially interesting since the Amuq Valley became an important center for metal production at the end of the fifth millennium B.C.E.,[54] though it is devoid of local copper ore resources. Accordingly, the Amuq Valley was probably the destination of the copper ore mined and the metal smelted at Degirmentepe. This assumption is strengthened by the existence of another important center for copper metallurgy and metalwork, Hacinebi, situated between the upper Euphrates mining area and the Amuq Valley (fig. 2). The extensive metallurgical findings discovered at

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[45] Crucibles were also identified in many other sites of early metallurgy in the southern Levant (Adams 2002; Levy et al. 2002; Hautpmann 2007, 240). It is the presence of slags in the crucibles (normally occurring during the process of purification of the smelted copper) that led to the conclusion about a crucible smelting process in Canaan.

[46] Levy et al. 2002. In this area, it is suggested that up to 5,000 tons of slag was produced during the Early Bronze Age.

[47] Özbal et al. 2000; Yener 2000, 34–6.

[48] Yener 2000, 42. At Degirmentepe, archaeological traces of smelting installations are not so important with regard to the quantitative importance of metallurgical findings. This suggests that Degirmentepe was a center specializing in the refining of the copper smelted in the surrounding mining areas.

[49] Özbal et al. 2000.

[50] Yener 2000, 39–42.

[51] Shugar 2000, 223–28. Hauptmann (2007, 299) also points to the compatibility of the finding of arsenical copper from the southern Levant with ores from the northern Euphrates. The addition of sulfide ores in the furnace, found at Beer Sheba but not at Timna (B. Rothenberg, pers. comm. 2009), is consistent with the contact, at this time, between the southern Canaanite homeland and the northern Euphrates area, where crucible cosmelting was practiced.

[52] Yener 2000, 43–4.

[53] Yener 2000, 34.

[54] Mallowan 1963.

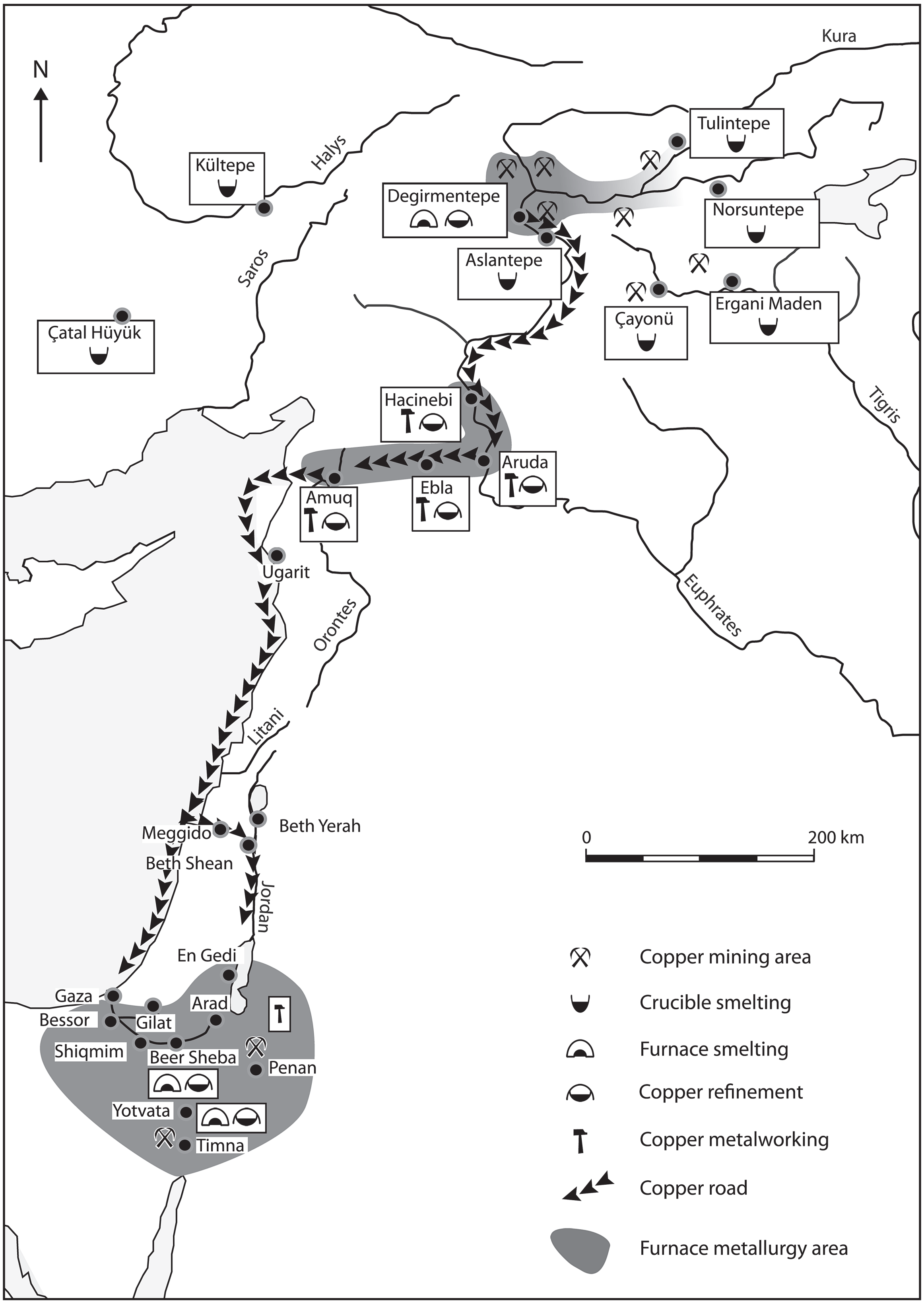

Fig. 2. Furnace metallurgy in the fifth millennium B.C.E. (drawing by P. Jean-Baptiste).

Hacinebi (ores, slags, crucibles, molds, furnaces, tuyères, and tools) suggest that this place (also devoid of copper ore resources) was another protoindustrial center that specialized primarily in copper purification and casting.[55] It seems, therefore, that Hacinebi and Amuq were settlements of metallurgists who specialized in the smelting, purifying, and working of the arsenical copper that originated in the northern Euphrates area and was exported to the southern Levant (see fig. 2). When considered together, all these observations suggest that the furnace metallurgy identified in the northern Euphrates area and the Amuq region originated in the southern Levant.

At the end of the fifth millennium B.C.E., the world of furnace metallurgy was, therefore, restricted to the southern Levantine homeland and its northern extension, from Amuq to the northern Euphrates,[56] both generating a Levantine core of furnace metallurgy.

Fourth Millennium B.C.E.

From the beginning of the fourth millennium B.C.E., the southern Levantine homeland of metallurgy was expanding toward the Sinai peninsula and the Eastern Desert area in Egypt. A considerable amount of the copper produced was sent to the Nile Valley and Delta.[57] At the same time, furnace metallurgy began appearing in many other areas (the Caucasus, the Iranian plateau, Anatolia, and the Aegean).

The Caucasus. Furnace metallurgy is found in the southern Caucasus from the early fourth millennium B.C.E. It appears a few centuries later in the northern Caucasus, at the earliest stages of development of the Maikop (Kurgan) culture. Both in the southern and northern Caucasus, an advanced technology of furnace smelting (large tuyères and furnaces, copper-free slags, intentional alloying) is always found.[58] It is likely, therefore, that furnace metallurgy was not a local development in the Caucasus.

Communication between the Levant and the Caucasus is evident during the Chalcolithic period, as shown by the introduction of grapes in Canaan and by the discovery at Shiqmim (southern Canaan) of horse bones (*Equus caballus*), an animal originating in the Eurasian steppes.[59] This suggests a spread, in the early fourth millennium B.C.E., of furnace metallurgy from the Levantine core toward the Caucasus. This hypothesis is supported by the following observations:

1. The earliest sites of Caucasus metallurgy (Murgul, Amiramis Gora, Thegut) are located in the southern and western areas,[60] that part of the Caucasus closest to the Levantine core (fig. 3).
2. Significant amounts (up to 12%) of antimony are found in many copper artifacts from the Nahal Mishmar hoard (ca. 3750 B.C.E.) produced in the southern Levant. The most probable source for this antimony is the mining region of Ghebi, in the southern Caucasus (see fig. 3).[61]
3. Similarities have been noticed between the material culture of Hacinebi and of the southern Caucasus sites of furnace metallurgy.[62]
4. The copper artifacts and stamps found in burial tombs (kurgans) from the Maikop culture of the northern Caucasus resemble those from the northern Euphrates culture of the early fourth millennium B.C.E.[63]

Consequently, it seems that furnace metallurgy had reached the southern Caucasus from the Levantine core a few centuries after its extension toward the northern Euphrates (see fig. 2).

Elam, Mesopotamia. A substantial increase in the production of copper artifacts has been observed at Susa at the beginning of the proto-Elamite period (ca.

[55] Beyond the finding of copperless slags (indicating a furnace true-smelting process), the presence of slags with copper prill inclusions and a high level of oxidation suggests that a process of metal purification (and eventually metal alloying) was performed in crucibles at Hacinebi (Özbal et al. 2000 [with references]).

[56] Later, these southern and northern Levantine poles of metallurgy were the source of two distinct metallurgical traditions coexisting in Canaan (Levy 1995; Muhly 1995, 1504). The northern tradition is characterized by the use of larger furnaces and crucibles than are used in the southern tradition, by the use of hand instead of foot bellows, and by the preferential use of bivalve molds for casting. Davey (1988) justifies the difference in traditions by the relative scarcity of charcoal in the semiarid climate of the southern Levant.

[57] A southern Canaanite metallurgical activity is attested in Sinai (Beit Arieh 1980; Rothenberg and Glass 1992), and the Beer Sheba culture extended its influence upon Predynastic Egypt (esp. in the Nile Delta) from the Late Chalcolithic period (Wenke 1991; Harrison 1993; Gophna 1995; Adams 2002). This included the trade of copper artifacts and ingots (Hauptmann 2007, 303).

[58] Kavtaradze 1999, 74.

[59] Levy 1995; Issar and Zohar 2007.

[60] Kavtaradze 1999. Many of these settlements are fortified (Kohl 1988), suggesting that they were inhabited by a foreign population.

[61] Concerning the presence of antimony in some of the Nahal Mishmar artifacts, see Tadmor et al. 1995; Golden et al. 2001. No significant sources of antimony exist in the Euphrates basin and the region of Susa, but polymetallic ores rich in antimony (up to 40%) have been identified in the Ghebi area (see fig. 3 herein), where traces of very ancient mining have also been observed (Kavtaradze 1999, 87).

[62] Lyonnet (cited by Kohl 2007, 70–1).

[63] Kohl 2007, 74–8. This linkage is also stressed by the Levantine influence observed on Transcaucasian culture (Gamkrelidze and Ivanov 1985).

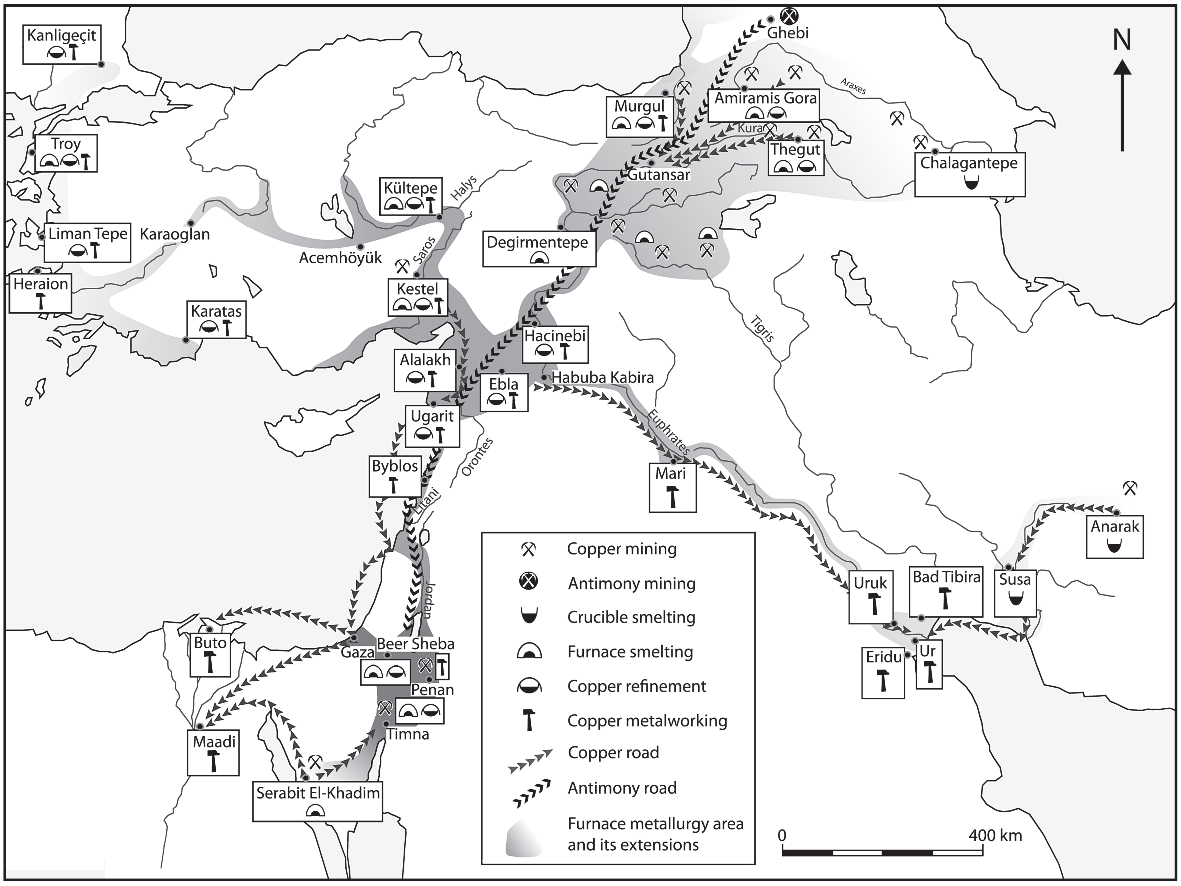

Fig. 3. Furnace metallurgy in the fourth millennium B.C.E. (drawing by P. Jean-Baptiste).

3500 B.C.E.). At the same time, crucible smelting was suddenly replaced by furnace metallurgy.[64] But the development of furnace technology was not a gradual process at Susa, suggesting, again, an exogenous origin. The Levantine influence is suggested both by the sudden emergence of a mature stage of the lost-wax technique of casting and by the style of the earliest artifacts produced in Elam by this technique.[65] Similarity of the seals found in the Levant and at Elam at this time confirms the idea of Levantine ascendancy on the Elamite furnace metallurgy.[66]

Western Anatolia, the Balkans, and the Aegean World. The presence of furnace metallurgy has been acknowledged in southeastern Europe from the end of the fourth millennium. Its sudden occurrence at a mature stage follows a long period of cultural regression, the so-called Balkan Dark Age characterized by the decline of copper production (crucible smelting) and the abandonment of many settlements.[67] In Greece and in the Aegean, furnace metallurgy suddenly appears at a mature stage of development at Kythnos, Naxos, Manika (Euboia), and in the mining area of Laurion.[68]

[64] Pigott 1999a, 79.

[65] Davey 1988; Moorey 1999, 256–57; Avilova 2008.

[66] Beck 1976; Lapp 1995. This intimate relationship between areas so far apart was possible via the Urukian network of exchange already linking Canaan to Sumer (Algaze 1993; Butterlin 2003; Philip 2003). Evidence of copper metallurgy is scarce at the earliest stages of development of Sumer (5000–3500 B.C.E.), as this area depended on the exogenous production of copper (Moorey 1999). In this context, it is likely that the Uruk expansion toward the northern Euphrates (ca. 3700 B.C.E.) was stimulated, at least partly, by an attempt to control copper production and trade from the Tigris-Euphrates basin. It generated a pathway of communication between the northern Euphrates area and the Iranian plateau, where copper was already being produced by crucible smelting.

[67] McGeehan-Liritzis 1983; Kohl 2007, 34.

[68] At Kythnos, one of the main sites of Aegean copper production during the Early Bronze Age, the remains of furnaces and of large amounts of slag have been identified from 3100 B.C.E. (Stos-Gale 1989; Davis 1992, 704, 717, 728).

In both cases, the pattern of emergence of furnace metallurgy suggests its introduction from outside.[69] The influence of the Levantine core on the emergence of the Aegean furnace metallurgy is suggested by traces of copper of northern Euphrates origin in Early Cycladic copper artifacts.[70]

Third Millennium B.C.E.

A widespread occurrence of furnace metallurgy is observed in the third millennium B.C.E. In cold areas of Central Asia and Europe, where copper resources are mainly sulfide ores, this development is related to the capacity to use them as the single source of copper. But an autonomous development of furnace metallurgy is unlikely. The use of sulfide ores is a complex process involving vast knowledge of furnace smelting (oxide ores) and of the use of fluxes.

During the third millennium B.C.E., furnace metallurgy also appeared in an area rich in tin ore resources (fig. 4). Nevertheless, the extensive smelting of tin ore observed there greatly exceeded local needs. This suggests that the emergence of furnace metallurgy in these areas is related to their integration in a network of tin production and trade.[71]

Central Asia. The spread of furnace metallurgy in Central Asia is related to the expansion of the northern Caucasian Maikop culture from the early third millennium B.C.E.[72] This evidence confirms that furnace metallurgy was not a local development in Central Asia. It also reveals that furnace metallurgy played an important role in the dynamics of the expansion of the Maikop culture.[73] This furnace metallurgy spread gradually toward southern Siberia (the Afanasievo culture of the Altai area) and the southeastern steppes of Central Asia (the Andronovo culture). Apparently, it reached the Xinjiang area (eastern China) independently from these two areas.[74] From the middle of the third millennium B.C.E., a new and important center of furnace metallurgy was developing in the Arkaim area, following the discovery of large ore deposits in the southern area of the Ural mountains.[75]

The Iranian Plateau and the Indian Ocean. During the third millennium B.C.E., a gradual movement of diffusion of furnace metallurgy is observed from the western to the eastern part of the Iranian plateau.[76] As in Central Asia, this diffusion of furnace metallurgy plays a prime role in the proto-Elamite expansion. It reached the eastern sites of crucible metallurgy from the Bactrian-Margiane area (modern Afghanistan).[77] From there, it expanded toward the north of the Indus Valley (see fig. 4).[78]

At the same time, furnace metallurgy suddenly crops up around the rich copper ore deposits of Magan (see fig. 4).[79] Magan copper production was rapidly integrated into an extensive network of copper trade and distribution including Sumer and the Indus Valley.[80] Furnace metallurgy emerged at Magan at an advanced stage of development, and its introduction from outside is supported by data pointing to contact between Magan, Sumer, and Elam during the Neolithic period.[81]

The Mediterranean Basin and Central Europe. In Crete, furnace smelting also appears suddenly in the third millennium B.C.E. at an advanced stage of development. An analysis of the chemical composition and style of the copper artifacts from the earliest period of furnace metallurgy there suggests relations with the Cycladic network of copper production, though copper of Levantine origin is also acknowledged.[82]

Furnace metallurgy was progressively expanding in the western part of the Mediterranean basin (Sardinia, Italy, southern France, and North Africa) (see fig. 4)[83]

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[69] Even Renfrew (1967, 14) assumed that "[t]he notion [of exogenous origin of Aegean metallurgy] conforms, however, to the belief that metallurgy came to the Aegean from the east. Whether its origins were in Mesopotamia or southern Anatolia, metal working was practiced in both areas well before its relatively sudden arrival in the Aegean."

[70] Gale et al. 2003, 127.

[71] E.g., Yener and Vandiver (1993) have described the rapid development of Kültepe (Taurus Mountains), an Early Bronze Age site of tin smelting. Its rapid integration in the Anatolian trade network linking the Taurus region of tin production with the Aegean, the Balkans, and the Amuq Valley is discussed by Sahoglu 2005.

[72] Kohl 2007, 59.

[73] Chernykh 1980.

[74] Jettmar 1980; Mei 2000, 58–60; Mei and Yanxiang 2003.

[75] Grigoriev (2000) mentions the affinities already observed between the Sintashta and Near East furnace metallurgy. This point is especially interesting when one remembers the importance of the transformations undergone in the Sintashta (metallurgical) culture during the Indo-European expansion, from the beginning of the second millennium B.C.E. (Sarianidi 1999; Jones-Bley 2000).

[76] Heskel and Lamberg-Karlovsky 1980.

[77] Thornton et al. 2002.

[78] Kennoyer and Miller 1999, 116–17. From isolation of metalworking areas from the Indus Valley settlements, Kennoyer and Miller (1999, 117) suggested: "It is possible that the Indus people themselves were not involved in the mining and smelting."

[79] Hauptmann et al. 1988; Blackman et al. 1989.

[80] Potts 1993.

[81] Carter 2006.

[82] Branigan 1968; Pryce et al. 2007. During the Prepalatial period in Crete, most of the copper originated from the Cyclades and Laurion, though some was imported from Arabah and even Elam (Kristiansen and Larsson 2005, 124).

[83] LoSchiavo 1988; Ambert 1999.

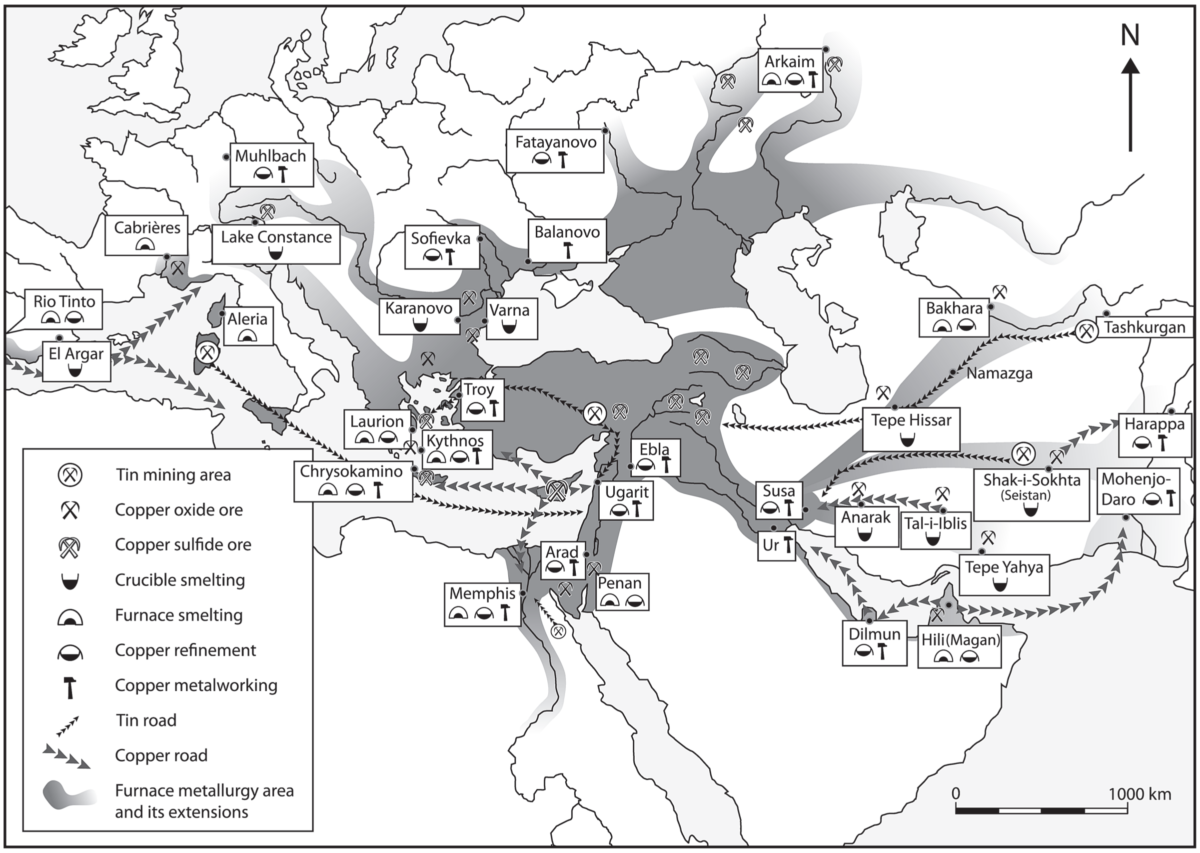

Fig. 4. Furnace metallurgy in the third millennium B.C.E. (drawing by P. Jean-Baptiste).

through a pattern that parallels the spread of the Bell Beaker culture. Also on continental Europe, furnace metallurgy was diffusing concurrently with the spread of the Bell Beaker culture.[84] Beyond their patterns of migration, the discovery of tools for metalworking and furnaces in Bell Beaker settlements confirms their involvement in the diffusion of furnace metallurgy.[85]

In the early third millennium B.C.E., furnace metallurgy made a sudden appearance at a very advanced stage in the southern Iberian peninsula (Rio Tinto). Settlements highly specialized in copper production are identified, and the quantity of slag points to extensive mining and smelting activity.[86] The process of copper production (smelting, purification, and casting) was specialized in a way that invokes the protoindustrial complex previously seen in the southern Levant. Nothing is known about the identity of these metallurgists, but their sudden emergence, their habitat in fortified settlements, their limited influence on the local culture, and their sudden disappearance at the end of the third millennium B.C.E. suggest that, also in this case, furnace metallurgy had no local origin.

Second Millennium B.C.E.

During the second millennium B.C.E., furnace metallurgy spread toward the limits of the ancient world: it reached the British Isles,[87] and two distinct paths (the Baltic Sea and rivers from central Europe) led to

[84] Harrison 1974; Price et al. 1998; Craddock 1999; Vander Linden 2007. According to Zoffmann (2000), the Bell Beaker people were aliens who did not mix with the indigenous Carpathian population.

[85] Gomori 1988; Brodie 1997; Price et al. 1998; Krause 2002; Sarauw 2007; Vander Linden 2007. Concerning the Mediterranean diffusion, the Bell Beaker people probably resided near the sites of furnace metallurgy already existing from the beginning of the third millennium B.C.E. Their continental diffusion via the Danube ties them to the furnace metallurgy from the Balkans.

[86] Nocete 2006.

[87] Tylecote 1986; Needham et al. 1989; Budd et al. 1992; Northover 1999.

Scandinavia and Finland.[88] Furnace metallurgy also expanded in North and sub-Saharan Africa,[89] where crucible smelting was apparently unknown. Via the Xinjiang area, furnace metallurgy originating in Central Asia rapidly expanded into China.[90] Furnace smelting later extended from China to Korea and reached Japan together with the introduction of the Yayoi culture from the mid first millennium B.C.E.[91]

After more than 1,000 years of copper production by crucible smelting, furnace metallurgy finally appeared in southwestern Asia during the second millennium B.C.E. (fig. 5). Here again, the rapid integration of this area into a wide network of tin production and trade suggests that furnace metallurgy is not indigenous.

This survey shows that, except in the southern Levant, furnace metallurgy—when it appeared—was always already at an advanced stage. Its chronological pattern of emergence reveals a dynamic of gradual diffusion from the Levantine core, rather than a local spread from sites of crucible smelting. Accordingly, the discovery of furnace metallurgy should be considered a single event progressively diffusing throughout the ancient world.

THE DYNAMIC OF EXPANSION OF FURNACE METALLURGY

In Anatolia, Central Asia, and northern/central Europe, the spread of furnace metallurgy results from the progressive enlargement of a metallurgical domain (an autonomous center of metal production integrated into a common network of forging/exchange/trade of metal artifacts).[92] In Europe, this dynamic is related to the slow and multidirectional pattern of migration of the Bell Beaker people,[93] suggesting that it is not directly motivated by the search for new mining resources. Rather, the expansion of a metallurgical domain looks like a combination of the desire of populations to join the metallurgical domain and the need, for the smiths, to migrate toward new horizons.[94] It is defined here as a centrifugal process of expansion.

In its earliest stages, the first furnace metallurgical domain (the southern Levant) did not gradually expand in all directions. On the contrary, new sites of furnace metallurgy appear at a great distance, near new ore resources (northern Euphrates, the Caucasus) and along the pathway linking them to the southern Levant domain of metallurgy (Hacinebi, the Amuq Valley area). In the southern Caucasus and northern Mesopotamia, small fortified settlements are encountered where furnace metallurgy was introduced.[95] The absence of a hierarchy in these settlements suggests that they are unrelated to any local social stratification. Rather, they look like small colonies of alien smelters. Their emergence seems motivated, first of all, by the supply of specific ores and alloys in the homeland. Therefore, this type of expansion of furnace metallurgy is defined here as a centripetal process.

In contrast to the slow and diffuse mode of centrifugal expansion, the centripetal mode is characterized by a very rapid advance in specific directions. This dynamic is not dependent on the mining resources around the initial homeland. Otherwise, it is difficult to explain why furnace metallurgy did not rapidly spread toward eastern Africa and the Arabian peninsula, where mining ore resources (copper, tin, gold) also existed. The earliest stages of centripetal expansion toward the northern Euphrates are akin to the network of obsidian trade from the Late Neolithic period, linking the southern Levant to Anatolia and the northern Euphrates area.[96] Even development of the Amuq Valley, a region devoid of copper mining resources, as the center of the metallurgical network linking the northern Euphrates and the southern Levant (see figs. 2, 3) is not random.[97] Prior to the devel-

[88] Tylecote 1992, 14. In both cases, it is interesting that artifacts made from native copper were produced for at least a millennium. This links the introduction of furnace metallurgy to these areas and the search for new copper ore resources.

[89] Miller and van der Merwe (1994) mention three independent ways for the introduction of metallurgy in Africa from the north during the second millennium B.C.E. (or even before): the Nile pathway (east African metallurgical traditions), the Sahara pathway (Niger metallurgical traditions), and the western pathway spreading metallurgy from the Atlantic coast.

[90] Mei 2000; Zhimin 2000.

[91] Park and Gordon 2007.

[92] Chernykh 1980; Brodie 1997; Sahoglu 2005.

[93] Price et al. 2004; Giblin 2009. This linkage between the spread of furnace metallurgy and migration of peoples is stressed by Brodie (1997, 309): "The technology of copper production was not something to be easily gained. To acquire a skill or a technical practice meant hiring a practitioner."

[94] This motivation inherent in specialized craftsmen is expressed in the recent traditions of metallurgists from Africa, where famine and conflicts among brothers is a common mythological motive. It is generally resolved by keeping the firstborn in the ancestral workshop and by the migration of the others toward new horizons (Seignobos 1991). Because the smiths do not engage in agricultural activities, the number of smith families a village may support is extremely limited.

[95] Kohl 1988; Kavtaradze 1999.

[96] Rosen et al. 2005.

[97] Nilhamm 2003, 26–9. From the middle of the sixth millennium B.C.E., this area developed its own cultural characteristics (Issar and Zohar 2007, 73–5), probably conditioned by long-range trade with the Tigris-Euphrates basin and the Taurus Mountains (Bressy et al. 2005). It is not surprising that during the third and the second millennia B.C.E., this region became the main center of the ancient world in the trade of

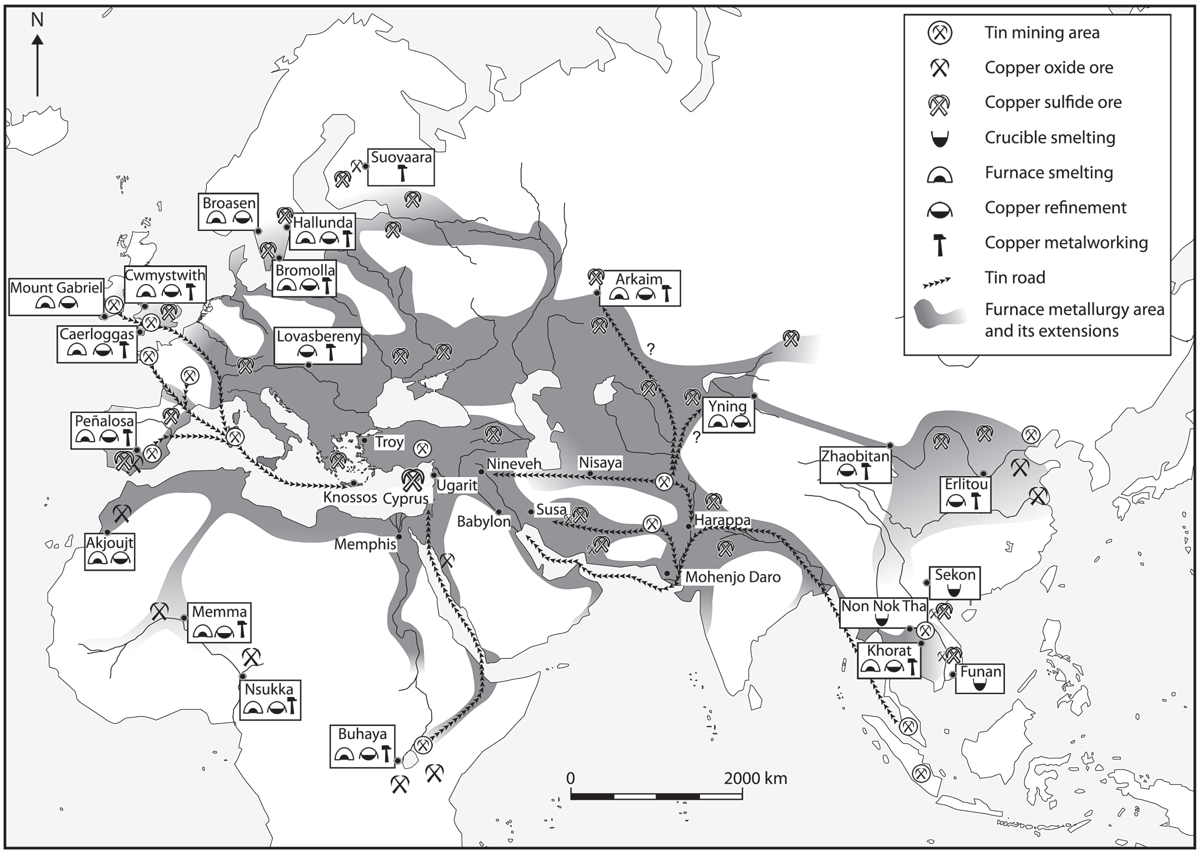

Fig. 5. Furnace metallurgy in the second millennium B.C.E. (drawing by P. Jean-Baptiste).

opment of furnace metallurgy, this region was already of central importance in the network of the trade and distribution of obsidian.[98]

The two processes of expansion of furnace metallurgy are certainly interrelated. An isolated colony of metallurgists (centripetal expansion) may stimulate the emergence of a new metallurgical province (centrifugal expansion). Reciprocally, smiths living in a metallurgical domain must have purchased copper or bronze ingots from smelters belonging to the wide metallurgical network.[99] But these two modes of diffusion are not systematically linked. In the northern Caucasus, for instance, the emergence of a metallurgical province results from its geographic isolation from the Levantine core, and its eastward expansion toward Central Asia (centrifugal process) occurred without the interaction with smelters involved in the centripetal process.[100]

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copper and tin (Muhly 1995).

[98] Bressy et al. 2005. Similarly, the pathway of diffusion of furnace metallurgy in the north of the Iranian plateau follows the lapis lazuli route linking the Indus Valley to the Near East during the Late Neolithic period (Crawford 1974).

[99] The existence of itinerant metallurgists supplying metal ingots to local metalworkers of central Europe has been noted for a long time (Schaeffer 1949; Hanfmann 1952) and confirmed by recent studies (Tylecote 1986, 10–24; Kristiansen and Larsson 2005, 108–16). The Levantine ascendancy of these itinerant smelters is stressed by the analogy of artifacts (and esp. specific neck-ring bronze ingots) unearthed at Ugarit and in central and western Europe (early second millennium B.C.E.). Later, Schaeffer-Forrer (1978) attempted to invert the direction of influence by assuming that the development of bronze metallurgy spread gradually from Europe to the Near East. But this claim is now barely tenable.

[100] This phenomenon is shown in the Caucasus. The southern Caucasian (Kura-Araxes) culture is characterized by small settlements fortified or perched on quite inaccessible places, with no social differentiation (Kohl 2007, 90–1). But the transfer of furnace metallurgy to the northern part of the Caucasus is followed by deep transformations: a strong social hierarchy appears in the Maikop culture of the northern Caucasus, characterized by royal tombs (kurgans) rich in copper and gold artifacts (Kohl 2007, 58–78). It is likely that the sudden concentration of power resulted from isolation of the northern Caucasus community of metallurgists from the Levantine network. This phenomenon is of considerable importance when considering the role of the Maikop culture in the emergence and development of the Indo-European world.

The opposite situation also occurs. During the third millennium B.C.E., the huge amount of copper produced in Magan did not transform it into the center of a new metallurgical domain expanding toward the southern Arabian peninsula and eastern Africa. Rather, it remained mainly a colony of smelters producing copper and exporting it to Mesopotamia and the Indus Valley (Meluhha).[101]

The highly developed center for copper metallurgy identified in the southeastern Iberian peninsula (third millennium B.C.E.) also reflects a centripetal process of extension, as seen in its fortified settlements inhabited by a population made up almost exclusively of specialists in metallurgy.[102] It is likely that most of the copper produced was sent far away. For these reasons, the influence of these colonies on the local culture remained surprisingly limited at the beginning of the third millennium B.C.E.[103]

According to the data presented here, the centripetal mode of diffusion of metallurgy was first located in the Levantine core. It is interesting, in this context, to point out that the overseas policy of the Canaanites, during the Bronze Age and Iron Age, was directly inherited from this pattern of diffusion. During the second and first millennia B.C.E., Canaanite colonies specializing in mining and the production of metals (copper, silver, gold, and tin) have been identified all around the Mediterranean basin, on the Atlantic coast, and east of Canaan.[104] Together, they generated an extensive network of exchanges that controlled a considerable portion of the trade in metals (esp. tin), from the Indus Valley to the Iberian peninsula.[105]

The dynamic of the spread of metallurgy is therefore complex. It results from the activity of two groups of metallurgists, the first being engaged in an extensive network of production and trade centered on the Near East, the second being locally involved in a progressive extension of a metallurgical domain and in the diffusion of the cultural changes inherent in the introduction of furnace metallurgy.[106]

Because of the integration of distant regions into a community of exchange of raw materials, metals, goods, innovations, and ideas, the two groups of metallurgists may be the source of the remarkable cultural homogeneity of the Bronze Age civilizations from Asia, the Near East, and Europe.[107]

THE SOCIOCULTURAL DIMENSION OF FURNACE METALLURGY

The growth of a metallurgical domain extended the area of diffusion of copper artifacts. In addition, it prompted important transformations in agriculture, habitat, way of life (the so-called revolution of the secondary products),[108] burial customs, and social structure. Many of these transformations are first seen in the Chalcolithic southern Levant,[109] suggesting their intimate bond with the emergence of furnace metallurgy.

Sociocultural changes inherent in the spread of furnace metallurgy have for some time been related to technological transformations, mainly in agriculture (hoe), carpentry (wheel, boats, machines), and architecture (stone cutting). However, this explanation is challenged by the fact that copper remained quite a rare metal until the middle of the third millennium B.C.E.[110] For this reason, it is difficult to explain the enormous influence of furnace metallurgy through the replacement of copper tools for those made of flint.

The technological transformations created by furnace metallurgy are quite similar in areas where cop-

[101] Potts 1993; Prange et al. 1999.

[102] Nocete 2006.

[103] Rovira 2002. Nevertheless, it may be that the expansion of the Bell Beaker culture from the Iberian peninsula, from the middle of the third millennium B.C.E., is concurrent with the massive presence of these alien smelters.

[104] Astour 1967; Kestemont 1983, 1984; Castro 2006.

[105] Documents from Ebla, Mari, Alalakh, and Ugarit reveal the importance of tin and cassiterite from countries as widely separated as the Indus Valley and the Iberian peninsula and of their trade all over the ancient Near East (Linder 1981; Muhly 1985; Stieglitz 1987; Pettinato 1995; Kristiansen and Larsson 2005, 114–20).

[106] The coexistence of local (*dactyls*, *couretes*) and foreign (*cyclopes*, *telkhine*) metallurgists is stressed in Greek mythology. The latter, mainly involved in smelting and the supply of metal ingots, are also considered *daimones* of Near Eastern origin (Blakely-Westover 2002).

[107] For a synthesis concerning the cultural homogeneity of distant Bronze Age civilizations, see Kristansen and Larsson 2005. The authors stress from the first page the central importance of the long-range network of trade and exchange in the Bronze Age world: "It is a point we wish to make that Bronze Age research is thereby missing an essential aspect of this epoch—the importance of journeys, of trade and interactions. This led to a widespread transmission and transformation of social institutions with a Near Eastern/Mediterranean background in large parts of Bronze Age Europe—it is perhaps the most characteristic element of that epoch."

[108] Sherratt 1983.

[109] Levy and Shalev 1989; Joffe and Dessel 1995; Levy 1995.

[110] The scarcity of copper artifacts unearthed from Chalcolithic and Early Bronze Age sites was justified by the continuous recycling of copper. The bias toward prestige artifacts in regard to utilitarian tools was similarly justified (by their symbolic value, prestige artifacts are less easily recycled than utilitarian tools). However, through an analysis of cut marks on butchered animal bones, Greenfield (1999) concluded that, in prehistoric southern Europe, metallic cutting tools were not commonly in use until the middle of the third millennium B.C.E.

per production was ignored (Egypt, the Caucasus, northern Europe, Central Asia, Vietnam, China)[111] or processed in crucibles (northern Euphrates, Anatolia, Balkans, Greece, Elam).[112] Accordingly, the transformations stimulated by furnace smelting do not appear directly related to the circulation of copper artifacts.

A look at traditional societies may help explain how furnace metallurgy may have provoked so many changes. In Africa, smelters and smiths are not only known as craftsmen; they also regulate the political power (from the instruction/coronation of the future leader to his resignation), and they ensure the exercise of justice and the arbitration of conflict. They also possess the secret knowledge of divination, sorcery, rain making, medicine, poetry, and rites of passage (birth, puberty, death).[113] This crucial role is reflected in many African mythologies, where the first metallurgist (generally coming from outside) is the civilizing hero par excellence.[114] The major importance of the metallurgist is similarly expressed by many ancient mythologies. In Greece, for instance, the civilizing hero (Prometheus, Phoroneus, Cadmos) is a metallurgist providing "divine knowledge" to humankind. Similarly, the smith god (Hephaistos) is a demiurge (creation of a woman and of automats) forging "magic tools" for the other gods (thus becoming the source of their divine power), and building the apparatuses of the divine city (the robots on Olympus described in Hom. *Il.* 1). The importance of legendary metallurgists and smith gods is extant in many other ancient world traditions.[115] Together, they suggest that the ancient metallurgists enjoyed a prestigious status similar to that recently encountered in Africa.[116]

Both in antiquity and in traditional cultures, smelters enjoyed a more prestigious status than smiths. For instance, the magic/divine dimension related to furnace metallurgy is associated with the smelting of ore rather than with metalworking.[117] It seems, therefore, that the civilizing impetus accompanying the spread of metallurgy is more related to the production of the metal itself than the artifacts. Yet this elevated status of the metallurgist is not observed in South America, where copper was produced by crucible smelting. This suggests that the civilizing dimension of metallurgy is intimately connected to the smelting of copper ore in a furnace.

Crucible smelting emerges in the context of purification of native copper from its mineral gangue. For this reason, the smelting of copper remains an extension of the purification of an already existing matter, native copper. At best, the smelter "accelerates" in his crucible a natural process of copper production. But furnace smelting emerged in a context devoid of native copper. For this reason, the production of copper in a furnace cannot be interpreted as an improvement/acceleration of any natural process of maturation. Rather, the first production of copper in a furnace was probably interpreted as a process of creation of a matter previously unknown, since the oxide ore from the southern Levant is totally devoid of native copper. In such a context, it is not surprising that the smelters became invested with demiurgic (magical) powers, encouraging them to transcend the boundaries of "existing matter," the universe given by the gods. As many ancient mythologies bear witness, this "Promethean attitude" is probably the source of the civilizing impetus accompanying, from its origin, the spread of furnace metallurgy.

CONCLUSION

The lack of a clear distinction between the furnace and crucible smelting processes was the singular de-

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[111] Chernykh 1980; Jettmar 1980; Zhimin 2000; Adams 2002; Kristiansen and Larsson 2005; Nguyen Giang Hai 2005; Kohl 2007.

[112] Caskey 1971; Ruiz 1993; Yener and Vandiver 1993; Nakou 1995; White and Pigott 1996; Rothman 2004.

[113] Levi-Makarius 1974, 108–44; Seignobos 1991.

[114] Tegnaeus 1950; Eliade 1977.

[115] In the book of Genesis (4), the first engendered man is named Cain, a term designating the metallurgist. This first smelter is also the founder of the first city. From his descendents, Tubal-Cain is the "father of the smiths" and Jubal the "father of poets and musicians." A similar link between metallurgy and poetry is encountered in Greece (Athena), in India (Saraswati), in the Celtic world (Brigit/Eithne), and in Finland (the brothers Ilmarinen/Vainamoinen). The civilizing aspect of metallurgists is stressed in Egypt by Aha/Menes, the first king devoted to Ptah, the god of Nop (Memphis) patronizing unification of the Upper and Lower Egypt. Also in Persia, Housheng is both the first king and the first smelter. For further examples, see Eliade 1977, 72–81; Amzallag 2008, 46–63. For comparison of the myths and rituals from Africa and ancient Greece, see Blakely 2006. The similarity between Mesopotamian and Greek myths relative to metallurgy is discussed by Penglase 1994, 197–229.

[116] The civilizing heroes from antiquity are rooted in the Bonze Age, while metallurgy is attested in central Africa from the Early Iron Age. But the cultic importance of copper in African cultures (de Barros 2000, 161) suggests that they are also rooted in Bronze Age traditions.

[117] The magical powers in ancient Greece were related to the semimythical smelters living apart in wild areas (*cyclopes*, *telkhines*), rather than the smiths (*couretes*, *dactyls*), living in the city (Blakely-Westover 2002). In many African cultures, the upper stages of initiation (and, by consequence, the highest powers) are strictly reserved for the smelters, while the smelting itself is regarded as a secret activity (see, e.g., Njoku 1991; Reid and MacLean 1995). For the magical element of metallurgy, see Budd and Taylor 1995; Martin 2005; Amzallag 2008.

tail, apparently insignificant, that prevented the amalgamation of all the archaeological data into a single theory. Crucibles and furnaces were thought to differ primarily in their size, so that a spontaneous evolution from crucible to furnace was assumed. But this postulate cannot justify the use of crucibles for such a long period of time or explain the absence of reactors with intermediate shapes and sizes between the crucible and the bowl furnace. Even more problematic was the direct emergence of furnace smelting in the southern Levant. This difficulty was generally resolved by first refuting the findings from Timna and then assuming that the classical sequence of evolution from crucible to furnace is also viable in the southern Levant. In such a context, it is not surprising that so many questions (such as the sudden occurrence of furnace metallurgy at an advanced stage everywhere outside of the southern Levant, the similarities existing among distant Bronze Age societies, and the privileged status of the smelter) remained unanswered.

This confusing situation is resolved as soon as crucible and furnace smelting are acknowledged to be two distinct and unrelated processes. This simple fact enables us to integrate the contradicting claims of the localizationist and diffusionist theories (discovery of copper smelting at many independent sites between the sixth and second millennia B.C.E., and diffusion of metallurgy from a single homeland from the fifth millennium B.C.E.) into a single framework—what I call the synthetic theory. It also permits us to identify the source of the cultural homogeneity of the Bronze Age civilizations and to point to the nature of the transformations stimulated by the discovery of furnace smelting.

By distinguishing between crucible and furnace smelting, the synthetic theory also asks for a reconsideration of the terminology currently in use for naming the beginning of the Copper Age. Since the emergence of crucible smelting in a Neolithic culture (where native copper is eventually worked) does not induce any significant shift, this stage should be termed "Eneolithic." The term "Chalcolithic" should be, therefore, reserved for the period of the earliest development of furnace metallurgy in the southern Levant and its earliest expansion (see figs. 2, 3). This use of a distinct term for the earliest stages of furnace smelting is justified because, in contrast to crucible smelting, the emergence of furnace smelting is accompanied by important cultural changes distinguishing this period from the Neolithic.

On the basis of this revised terminology, four distinct situations may be noted concerning the introduction of furnace metallurgy: (1) transition from Eneolithic to Chalcolithic (northern Euphrates, Elam); (2) transition from Eneolithic to Bronze Age (the Balkans, the Aegean, the Iberian peninsula, the east Iranian plateau, Thailand); (3) transition from Neolithic to Chalcolithic (Nile Valley, south Caucasus, Mesopotamia); (4) transition from Neolithic to Bronze Age (north Caucasus, northern Europe, Central Asia, China). In all likelihood, the introduction of furnace metallurgy did not have identical consequences in the four cases considered here. However, in all of them, it brought about profound changes that deeply influenced the emergence of the Bronze Age societies.

SHANI-LIVNA 13
90411 ISRAEL
NISSAMZ@BGU.AC.IL

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