FORUM ARTICLE

A Chalcolithic Error: Rebuttal to Amzallag 2009

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Abstract

In the October 2009 issue of the *AJA*, Amzallag published a hypothesis for the origins and spread of furnace-based metallurgy in the Old World ("From Metallurgy to Bronze Age Civilizations: The Synthetic Theory," *AJA* [2009] 497–519). Amzallag's paper is rife with misunderstandings of both an archaeological and a technical nature, leading to a skewed vision of early metallurgical development. In this rebuttal, we seek to correct some of the more egregious errors in his article and provide a counterargument for the origins of copper-based metallurgy in the Old World.

INTRODUCTION

At the Society for American Archaeology meeting in 2008, Thornton argued that studies of the development of metallurgy in the Old World are constrained by a persistent "linear trajectory" model.[1] This model presents a historical narrative in which the early use of native copper led to the smelting of "pure" copper oxides, then to the smelting of impure oxides (which produced slag as a waste product), and eventually to copper sulfide smelting in larger furnaces. Thornton suggested that this linear model derives from an idealized scheme for the development of metallurgy in lowland regions of the Near East in general, the Levant in particular. He called this persistent archaeometallurgical narrative the "Levantine Paradigm" and argued that this model should not be extrapolated to other regions that might have different developmental sequences due to varying geological, ecological, and sociocultural contexts.

At the time, the Levantine Paradigm was constructed as an amalgamation of different viewpoints—a conceptual chimera—with no explicit exemplars in the published literature. Amzallag's recent article in the *AJA*, "From Metallurgy to Bronze Age Civilizations: The Synthetic Theory," actually exemplifies all the problems of the Levantine Paradigm.[2] It relies upon syllogistic arguments and misconstrued data to construct a historical narrative very similar to the linear model discussed by Thornton. We feel it important to provide a rebuttal to set the record straight for the wider archaeological audience.

Here we examine a few key issues that Amzallag addressed but misrepresented. First, we comment upon his technical discussion of crucible vs. furnace smelting technologies, so critical to his assertion that Levantine metalworkers brought furnace-based metallurgy to the rest of the Old World. Second, we discuss his archaeological timeline for the development of metallurgy, focusing especially on the Levant and Southeast Asia. We address the Levant because Amzallag grounds much of his argument on controversial data from this region, and we discuss Southeast Asia because it serves as an example of another region whose developmental trajectory Amzallag misinterprets. A complete list of errata would overwhelm this article.[3] The interested reader is encouraged to seek out some of the classic synthetic works on the origins of metallurgy[4] to obtain a more accurate picture of early metallurgical development in the Old World.

CRUCIBLE VS. FURNACE SMELTING

Amzallag claims that other scholars have created inaccurate pictures of early metallurgical development in the Old World because they did not understand the difference between crucible and furnace smelting technologies.[5] He argues that the former developed

Editors' note: We invite readers to participate in further discussion on the issues examined here by visiting the *AJA* Web site (http://www.ajaonline.org), under "AJA Online Forum."

[1] Thornton 2009a, 2009b.

[2] Amzallag 2009.

[3] In every figure and throughout the text, Amzallag places sites in the wrong countries (and millennia), he misrepresents the ore sources in particular regions, he confuses the metallurgical data in different areas, and he incorrectly supports nearly all his statements with citations that have no relation to what he writes.

[4] E.g., Wertime 1964; Muhly 1988; Chernykh 1992; Linduff et al. 2000; Craddock 2001; see also papers in Wertime and Muhly 1980; Maddin 1988; Mohen and Eluere 1991; Hauptmann et al. 1999.

[5] "The problem, I argue, arises because previous scholars did not distinguish properly between two modes of copper production: crucible metallurgy and furnace smelting" (Amzallag 2009, 497).

out of native copper melting and appeared in multiple regions independently, while the latter was invented once (in the southern Levant) and from there spread to the rest of the Old World. While the author is correct in saying that crucible and furnace technologies have often been conflated in the literature, he himself makes a number of incorrect assertions about the technical mechanisms of crucible smelting and furnace smelting that require correction.[6]

Crucibles, he argues, were first used to melt native copper and then later used to smelt "very high grade" copper oxide ores.[7] These crucibles, he asserts, were heated externally,[8] thereby limiting the temperature within the crucibles but maximizing their useable volume. Such externally heated crucible smelting would result in a very low yield of copper metal per "charge" (i.e., the combination of ores, fuels, fluxes, and anything else added together within a reaction vessel), on the order of 15 to 30 g.[9] He further suggests that no charcoal was being added to the ore charge within the crucible because of its small size. Thus, the reduction of copper oxide to copper metal was instead achieved by a cosmelting reaction between copper oxide and copper sulfide at about 1,200°C and under weakly reducing conditions.[10] These sulfide ores, however, were often of lesser purity than the oxide ores, so iron and silica fluxes were required to separate the metal from the mineral gangue via the formation of slag. Given that the small size of crucibles made it nearly impossible to include both ores and fluxes in the smelt without greatly reducing the already small yield, Amzallag argues that crucible smelting was an inefficient process disliked by ancient metalworkers.[11]

There are two fundamental flaws in Amzallag's argument. First, there is as yet no actual evidence that native copper was melted and cast prior to the invention of smelting.[12] Microscopic studies ("metallography") can firmly distinguish between native copper and smelted copper even if extensively hammered, but such studies cannot distinguish between native copper and smelted copper once it has been melted and cast.[13] For example, the sixth-millennium B.C.E. macehead from Can Hasan, long considered to be an early cast object,[14] was some time ago shown to be hammered from native copper.[15] Thus, the extraction of native copper from its host rock through melting in a crucible is an invention not supported by any archaeological evidence. The idea of native copper melting leading to copper ore smelting reflects an earlier—but now clearly outdated—view of gradual technological development.[16]

Second, and in stark contrast to Amzallag's claims, all early metallurgical crucibles studied over the last half-century or so were found to have been fired from above or inside, using charcoal as an integral and substantial part of the charge (fig. 1). This is clearly visible from the occurrence of slag, metal droplets, and vitrified ceramic only on the inside of the crucibles, while the outside shows no such heat impact. If early crucibles were fired from the outside, they should show a complete firing and vitrification throughout the body, as Roman and medieval crucibles do. Internal heating of crucibles is even well-documented from early Levantine settlements, such as the fourth-millennium B.C.E. copper melting crucibles from Tell esh-Shuna,[17] the melting and smelting crucibles from Abu Matar,[18] and the melting and smelting crucibles from Levantine mining sites such as Wadi Fidan 4 and Feinan in Jordan,[19] or Timna in Israel.[20] Internally heated crucibles are also documented in other early metallurgical regions, such as Chalcolithic Spain, Iran, the Aegean, the Balkans, and Thailand, to name but a few.[21]

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[6] As noted by one of the anonymous reviewers for the *AJA*, Amzallag also misunderstands the fundamental difference between melting and smelting. Melting refers to a change in the state of the substance (i.e., from solid to molten copper), while smelting refers to a change in the actual substance by means of a chemical reaction (e.g., from copper ore [a rock] into copper metal [a plastic and malleable material] by means of reaction with the carbon monoxide that is released by the combustion of charcoal).

[7] "It seems, therefore, that crucible smelting was discovered in the context of extraction of native copper from its mineral gangue by melting" (Amzallag 2009, 498).

[8] He refers 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)" (Amzallag 2009, 501).

[9] Amzallag 2009, 502, fig. 1.

[10] Amzallag 2009, 501.

[11] "[F]urnace smelting, as soon as it came into being, immediately replaced crucible smelting" (Amzallag 2009, 500).

[12] As pointed out by one of the anonymous reviewers for the *AJA*, there is also no evidence that the earliest metalworkers achieved temperatures high enough (1,083°C)—or maintained these high temperatures for long enough—to fully melt native copper.

[13] Maddin et al. 1980; Wayman and Duke 1999.

[14] French 1962.

[15] Yalçin 1998.

[16] E.g., Wertime 1973.

[17] Rehren et al. 1997.

[18] Shugar 2000, 99–100.

[19] Adams and Genz 1995; Hauptmann 2007.

[20] Rothenberg 1988, 195; Tite et al. 1990.

[21] For Spain, see Müller et al. 2004. For Iran, see Hauptmann et al. 2003, 206; Frame 2004; Thornton 2009a. For the Aegean, see Oberweiler 2005. For the Balkans, see Ryndina et al. 1999, 1064. For Thailand, see Vernon 1996–1997, 1997; Pryce 2009.

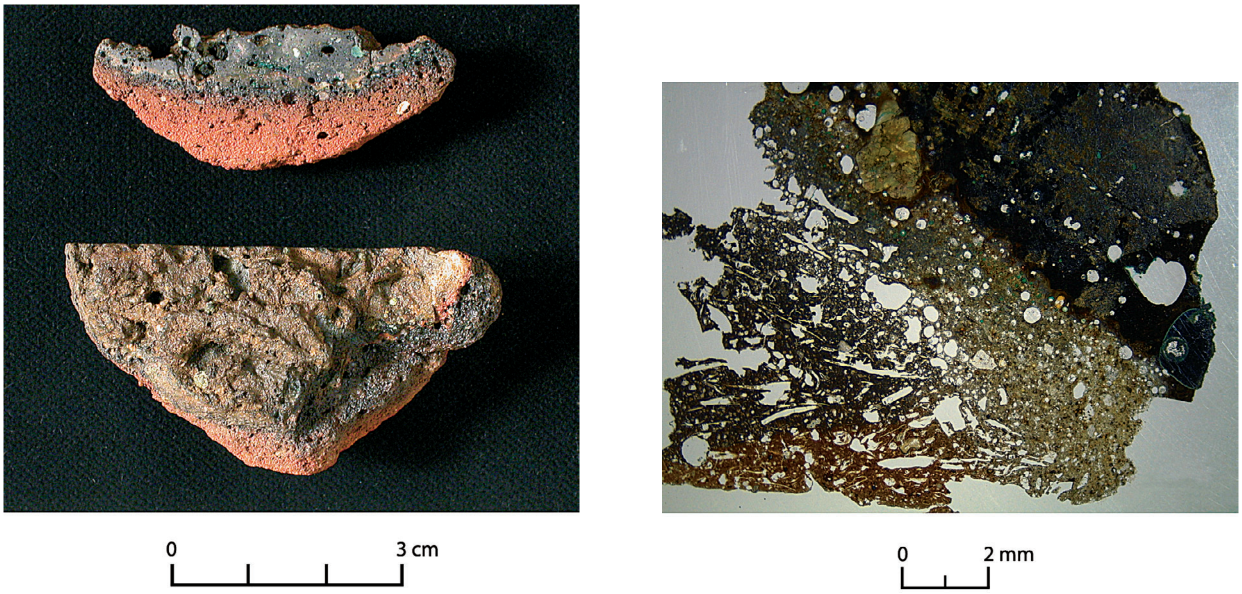

Fig. 1. Two examples of internally heated crucibles from the Near East: *left*, New Kingdom crucible from Qantir/Pi-Ramesse in the eastern Nile Delta, showing the slagged interior surface of the crucible and the relatively untouched exterior surface; *right*, cross-section of a smelting crucible from the Chalcolithic site of Tal-i-Iblis in southeastern Iran, showing the heat-alteration gradient of the ceramic from the black glassy slag on the interior to the pink unaltered ceramic on the exterior (Frame 2009, 606; courtesy L. Frame).

The exclusive heating of crucibles from above/inside has been highlighted in the past as a general characteristic of pre-Roman crucible metallurgy, regardless of whether the crucibles were used for smelting or melting.[22] Only very recently has the first externally heated metallurgical crucible been identified from a prehistoric context.[23] This unique steatite-based crucible from Tepe Hissar (northeast Iran) was used for the processing of lead-rich copper-arsenic metal and was found among numerous fragments of internally heated crucibles for regular copper smelting and melting. As a final note on Amzallag's discussion of crucible smelting, the mass estimates for copper metal put forward by him[24] are in stark contrast to those reported in the archaeometallurgical literature, including those from papers that he cites.[25]

Amzallag then presents furnace smelting as a fundamentally different metallurgical operation, with no relationship to the earlier crucible metallurgy.[26] He argues that furnaces are larger than crucibles and can therefore hold ore, charcoal, and fluxes within the reaction vessel itself. The larger volume and improved facilities for slag production provided by furnaces allowed for much higher yields of copper metal and the production of copper alloys (e.g., arsenical and antimonial copper) from the use of polymetallic sulfide ores. No longer did ancient metalworkers have to rely upon high-temperature cosmelting reactions; in furnace smelting, he suggests, the prior roasting of sulfide ores and the larger volume of the reaction vessel allowed for the increased production of copper and copper alloys from lower-grade ores.[27]

Several objections must be made to Amzallag's assertions regarding the development of furnace smelting vis-à-vis crucible smelting. For example, crucible smelting traditions in different regions are known to

[22] Rehren 2003; Bayley and Rehren 2007.

[23] Thornton and Rehren 2009.

[24] "[T]he small volume of a crucible does not allow the smelting of more than a few grams of copper" (Amzallag 2009, 501).

[25] E.g., Ryndina et al. (1999, 1064) who suggest a capacity for their Chalcolithic crucibles of 1,710 g of copper metal.

[26] "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 charcoal) be considered a spontaneous extension of crucible smelting, a process developed in a context of the purification of native copper" (Amzallag 2009, 501–2).

[27] Amzallag 2009, 502–3.

have used either purely oxidic ores[28] or mixed oxidic-sulfidic ores.[29] The presence of sulfides in crucibles does not necessarily suggest the intentional mixing of oxidic and sulfidic ores (i.e., cosmelting), nor does the presence of sulfides in furnaces suggest prior roasting steps. Instead, sulfides may have entered the crucible or furnace unintentionally as remnant phases in the oxide/carbonate gossans that form over sulfide deposits (i.e., "mixed smelting").[30] This is supported by evidence from sites such as Shahr-i Sokhta (Iran), where the resulting copper sulfide phase (called "matte") of a mixed smelting operation was discarded together with the slag rather than being retained for further processing to copper metal (fig. 2).[31]

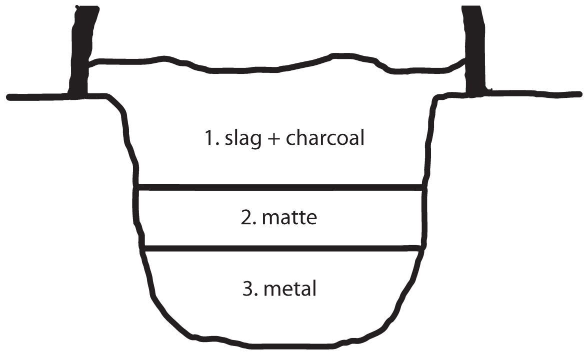

Fig. 2. A simplified diagram, showing the three resulting phases of an ideal copper-sulfide smelt: *1*, silicate slag; *2*, copper-rich matte (molten copper sulphide); *3*, copper metal (adapted from Thornton et al. 2009, fig. 1).

It should also be noted that cosmelting of oxides and sulfides will not work without the direct presence of charcoal inside the crucible. First, the amount of energy/heat released by the reaction of sulfides and oxides is not sufficient to compensate for the relatively high heat loss caused by the small volume of the crucible relative to its large surface area. Thus, the cosmelting reaction must be ignited with, and sustained by, heat generated from burning charcoal in direct contact with the minerals. Second, almost all early crucibles were made from poor clays that could not maintain their material and structural integrity in the presence of high temperatures and reactive chemicals.[32] Thus, if cosmelting operations had been attempted at 1,200°C with external heating, as Amzallag suggests, the crucible walls would have melted and collapsed long before the metal had been produced.

On a more general level, the old idea that copper sulfides occurred only rarely in prehistoric crucible smelting is no longer tenable, based on evidence from a number of regions in the Old World.[33] Whether these sulfides were being deliberately mixed with oxide ores or not remains uncertain, but we can no longer discount the idea of "sulfide smelting"[34] occurring within a crucible-based smelting tradition. Furthermore, the idea that alloying agents such as arsenic or antimony were found only in sulfide ores is not true.[35] Such elements are frequently found (as arsenates or antimonates) in oxide/carbonate ore deposits (gossans) overlying polymetallic sulfide deposits and are often cited as the main source of arsenic in early arsenical copper production.[36] Finally, as has been pointed out previously,[37] there is no direct evidence in the Near East for the deliberate addition of fluxes in metal smelting before the Middle Bronze Age. Thus, crucible and furnace smelting processes were carried out in this region for at least two millennia before intentional fluxing became common practice. This was because iron oxides and silica are often present, along with copper carbonates, in the gossans over sulfide ore bodies, and thus inevitably formed part of the smelting

[28] E.g., in Chalcolithic Spain (Rovira 2002; Müller et al. 2004).

[29] E.g., in Early Bronze Age Iran (Hauptmann et al. 2003).

[30] In the original treatise on cosmelting (Rostoker et al. 1989), the authors make it clear that they use the term "cosmelting" to refer to both intentional and unintentional mixing of oxidic and sulfidic ores. More recently, archaeometallurgists have tended to use the term "cosmelting" to refer to the intentional mixing of these ores, while "mixed smelting" is the more general term used when the intentionality of the ancient metalworker remains ambiguous.

[31] Hauptmann et al. 2003.

[32] Contrary to Amzallag's (2009, 501) rather general use of "refractories" to refer to "crucible, furnace, and tuyères fragments," very few prehistoric ceramics were actually "refractory" in the true sense of the term (i.e., able to withstand high temperatures without fusion or decomposition). We use "technical ceramics" as the more general term for early crucibles, tuyères, and furnace fragments, and reserve the term "refractories" for those ceramics that were able to withstand heat and aggressive chemicals better than the usual ceramics used at the time. The conscious selection of refractory clays over common pottery clays began in the late first millennium B.C.E.

[33] E.g., Bourgarit 2007; Pryce and Pigott 2008; Thornton 2009b.

[34] Either (1) roasting copper sulfides to copper oxides and then smelting the oxides to produce copper metal or (2) smelting copper sulfide ores to extract copper matte (pure sulphides); and then further processing the matte to produce copper metal.

[35] "[A]rsenic, an element generally present in sulfide but not in oxide ores" (Amzallag 2009, 501).

[36] E.g., Budd and Ottaway 1991; Budd 1993.

[37] Hauptmann 2007, 18–27.

charge, giving rise to so-called self-fluxing ores. Slag can also form through reaction of iron oxides in the charge with the technical ceramics used to construct crucibles and furnaces.

Thus, apart from the difference in volume (which Amzallag greatly exaggerates), his key difference between crucible and furnace technology is not the choice of ore (sulfidic or oxidic), but the source of heat: external for crucibles, internal for furnaces. We have shown that this dichotomy is a false one. This leaves us only the issue of the development of furnace technology out of crucible smelting to discuss. Here it is important to recall the numerous examples of metallurgical installations that are transitional from crucible to furnace, such as those presented from the Levant or the Aegean[38]—both areas cited by Amzallag but misrepresented or misunderstood by him. We assert, based on these data as well as on the technical objections that we have raised above, that furnace smelting did arise out of crucible smelting and that the two are not as different as Amzallag claims.

Besides the numerous technical problems with Amzallag's contrast between crucible and furnace smelting, it is important to emphasize that the strict dichotomy between crucible and furnace smelting is entirely unsupported by archaeological research. For example, Thornton has recently documented two entirely different metallurgical traditions from contemporaneous neighborhoods at Tepe Hissar, a Chalcolithic site in northeastern Iran.[39] In a domestic area of the site, analysis of numerous smelting crucible fragments and metallurgical slags has demonstrated a highly developed tradition for the production of arsenical copper without the use of furnaces.[40] Only 100 m away, in an area of multicraft workshops, analysis of contemporary furnace fragments and slags has demonstrated a well-established tradition for the production of copper, leaded copper, and lead for probable export. The critical point here is that complex crucible and furnace smelting technologies were carried out in different parts of the same settlement for more than 500 years, with no evidence of social or cultural differences between the metalworkers from the two areas.[41]

In conclusion, we argue (1) that Amzallag's characterization of early crucibles as externally heated is erroneous, and (2) that his subsequent pronouncement that there is no relationship between prehistoric crucible and furnace smelting is inaccurate. In fact, in multiple regions in the Old and New Worlds,[42] the local transition from crucible smelting to furnace smelting has been well documented.[43] His assertion that furnace smelting appeared "suddenly" in multiple areas of the Old World is unsupported by copious archaeological evidence, which is too extensive to be cited here. In regions where transitional installations are not yet known, it is likely that this is because of the lack of systematic surveys and the limited chronological resolution provided by archaeological methods at these early periods.

THE DEVELOPMENT OF METALLURGY IN THE OLD WORLD: TWO EXAMPLES

The major thrust of Amzallag's article is that crucible smelting arose in multiple areas around the world as an extension of native copper melting, while furnace smelting developed in one area (the Levant) with no prior tradition of native copper melting or crucible smelting.[44] He argues that Levantine metalworkers who were skilled in furnace smelting then migrated throughout the Old World (from Ireland to Japan, Thailand to sub-Saharan Africa) in search of new ore sources and distant trade markets.[45] He suggests that the "intrusive" appearance of furnace metallurgy in these far-flung regions shows "a dynamic of gradual diffusion from the Levantine core, rather than a local spread from sites of crucible smelting."[46] He then states that "the growth of a [pan-Old World] metallurgical domain . . . prompted important transformations in agriculture, habitat, way of life . . . burial customs, and social structure. Many of these transformations are first seen in the Chalcolithic southern Levant."[47] In other words, Amzallag infers that the expansion of furnace metallurgy from the Levant to the rest of

[38] Golden et al. 2001 (the Levant); Pryce et al. 2007 (the Aegean).

[39] Thornton 2009a, 2009b.

[40] Thornton et al. 2009.

[41] In fact, the lack of social differentiation between these two areas of Hissar may suggest that the exact same metalworkers may have been performing different metallurgical practices: the domestic tradition for locally consumed arsenical copper, and the industrial tradition for exported copper, copper-lead, and lead (silver?) products (Thornton 2009a).

[42] Amzallag (2009, 500) is quick to assert that furnace metallurgy never developed in South America, which is blatantly wrong. Shimada and Merkel (1991) refer to more than 100 metallurgical furnaces at the pre-Columbian site of Batán Grande in northern Peru, and Killick is currently studying copper smelting furnaces from the adjacent Ynalche Valley.

[43] E.g., Golden et al. 2001; Helwing 2005; Shimada and Wagner 2007.

[44] Amzallag 2009, 502–3.

[45] Amzallag 2009, 504–11; see numerous references throughout his article to "colonies of alien smelters" (e.g., p. 510) or a "colony of smelters" (e.g., p. 512).

[46] Amzallag 2009, 510.

[47] Amzallag 2009, 512.

the Old World corresponds “coincidentally” with the appearance of social complexity and “civilization” in these diverse regions.

As with his technical arguments, there are numerous problems with his archaeological reconstruction for the spread of metallurgy in the Old World. These cannot be explored in great detail here. Readers who wish to know more about the origins of metallurgical technologies in various regions are encouraged to read the new syntheses presented in recent editions of the *Journal of World Prehistory* and *Antiquity*.[48] In the meantime, we summarize here the development of metallurgy in the Near East to correct his view as seen from the Levant.

Contrary to Amzallag’s assertion that the Anarak mining region of Iran displays the earliest evidence of copper metallurgy, the first use of native copper in the world is actually from sites in eastern Anatolia such as Cayönü Tepesi, dated ca. 8000 B.C.E.[49] By the late eighth millennium, native copper usage appeared in the northern Levant (Tell Ramad) and in southwestern Iran (Ali Kosh), but both may have been imported along with obsidian from eastern Anatolia.[50] The earliest evidence for crucible-based smelting has been found in the Balkans dated to the mid–late sixth millennium B.C.E.[51] and in southeastern Iran ca. 5200–4500 B.C.E.[52] Interestingly, copper smelting does not appear in many other regions of the Near East until the mid–late fifth millennium B.C.E.[53] It is at this time that the Levant becomes one of several important “heartlands” for early metallurgy.

With regard to copper smelting in the southern Levant, Amzallag states, “Also noteworthy in southern Levantine metallurgy is the occurrence of furnaces from its earliest stages (Timna, fifth millennium B.C.E.).”[54] In actuality, the scholars working at Timna have suggested that there is evidence for sixth-millennium smelting at the site,[55] but this is beside the point. The argument for fifth- (or sixth-) millennium furnaces at Timna has been rejected for two major reasons.[56] First, the archaeological evidence used to date the early furnaces at Timna is strained at best. For example, according to Amzallag, “The earliest furnace unearthed at Timna (site F2) is extremely archaic in its size and shape.”[57] In addition, he writes, “Chalcolithic furnaces also have been identified at Beer Sheba (Abu Matar, ca. 4200 B.C.E.). 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.”[58] Such “evolutionary” arguments have been abandoned in archaeology since the 1960s, whether discussing ceramic types or slag types. New and more empirical evidence is needed before the proposed early date of the Timna furnaces will be accepted by most archaeologists.

Second, and more importantly, it has been well established that there is no copper in southern Levantine sites prior to ca. 4200 B.C.E.[59] By the early fourth millennium B.C.E., the evidence from Chalcolithic sites such as Abu Matar, Bir es-Safadi, and Shiqmim suggests the use of simple smelting installations characterized by pit-bowl furnaces roughly 30 cm in diameter flanked by a ceramic “collar” about 10 cm high (fig. 3).[60] These installations, or “proto-furnaces,” likely date no earlier than 3800 B.C.E., and there is no evidence for more developed furnaces in this region for centuries thereafter.[61] Only by the Early Bronze III period (ca. 2500–2300 B.C.E.) do we see a significant change in the metallurgical tradition of the southern Levant, as metal production became large-scale, centralized, and furnace-based.[62] The slag and copper produced in the earlier Chalcolithic pit/bowl furnace smelting installations can hardly be cited as evidence for advanced furnace-based smelting technology. On the contrary, they betray a rather primitive technology (relative to other contemporaneous regions of the Near East such as Anatolia, the Caucasus, and Iran) that in no way represents the “invention” of the furnace.

Amzallag’s misleading discussion of the early smelting in the Levant precedes an equally misleading treatment of the origins of metallurgy in various regions of the Old World. We focus here upon Southeast Asia as one of the most distant from the southern Levant. All regional specialists agree that the appearance of cop-

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[48] *Journal of World Prehistory* 22(3–4); Roberts et al. 2009.
[49] Muhly 1989; Maddin et al. 1999.
[50] Renfrew et al. 1966.
[51] Sljivar 2006; Radivojević 2007; Boric 2009.
[52] Pigott 1999b; Pigott and Lechtman 2003; Thornton and Lamberg-Karlovsky 2004; Frame and Lechtman (forthcoming). Frame’s reconstruction of crucible smelting techniques at Tal-i-Iblis is that crucibles were placed in hollows in the ground, filled with ore and charcoal, and then covered with charcoal—similar to the late fifth-millennium “protofurnaces” from Shiqmim in the Levant (Golden et al. 2001, 952).
[53] Yener 2000; Courcier 2007; Thornton 2009b.
[54] Amzallag 2009, 503.
[55] E.g., Rothenberg and Merkel 1995; Merkel and Rothenberg 1999; Rothenberg et al. 2003.
[56] Craddock 2001, 156; Hauptmann and Wagner 2007.
[57] Amzallag 2009, 503.
[58] Amzallag 2009, 503.
[59] E.g., Weisgerber and Hauptmann 1988; Hauptmann 1989, 1991, 2000; Levy 1995; Golden 1998; Genz and Hauptmann 2002; Rowan and Golden 2009.
[60] Shugar 2000; Golden et al. 2001.
[61] E.g., Levy et al. 2002; Segal et al. 2002, 2004.
[62] Levy and Shalev 1989; Shalev 1994; Craddock 2001.

per/bronze metallurgy in Southeast Asia was not an indigenous development but rather one with an external source.[63] Thus, Amzallag's reference to Thailand as a "homeland" of crucible-based metallurgy[64] suggests a lack of understanding of metallurgical developments in this region. Crucible smelting did not appear independently in Thailand; instead, the Southeast Asian crucible is most probably part of a smelting/casting "kit" originating among earlier metalworking peoples of the Eurasian steppe.[65]

Amzallag states that "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."[66] In fact, the earliest production of copper/bronze artifacts in Thailand involved both utilitarian and decorative items (e.g., personal ornaments), with the latter being produced in larger numbers.[67] He is correct in suggesting that metallurgy appeared in Thailand within a heterarchical sociopolitical context (although in the early–mid second millennium B.C.E.). By the mid first millennium B.C.E., however, strong indications of accelerating social complexity become increasingly apparent in tandem with indigenous developments in metallurgical technologies.[68] So, in fact, prehistoric society in Thailand ultimately "evolved" in a more hierarchical and socially complex direction in part because of the increase in metallurgical production.

Amzallag also appears to have misunderstood the chronology of Southeast Asian metallurgy, as is apparent in his table 1, where he lists Thai sites such as Non Nok Tha and Khao Phu Kha as having crucible-based metallurgy in the fourth millennium B.C.E.[69] Copper and bronze metallurgy appears in northeast Thailand, at the earliest, in the second millennium B.C.E.[70] Furthermore, Khao Phu Kha is a copper-rich mountain located in the Khao Wong Prachan Valley of central Thailand.[71] The copper smelting site of Nil Kham Haeng, however, is located at the base of Khao Phu Kha in the Khao Wong Prachan Valley. Either way, Southeast Asia was neither a "homeland" of independent crucible smelting technology in the fourth millennium B.C.E. nor a recipient of Levantine furnace technology in the second millennium B.C.E.

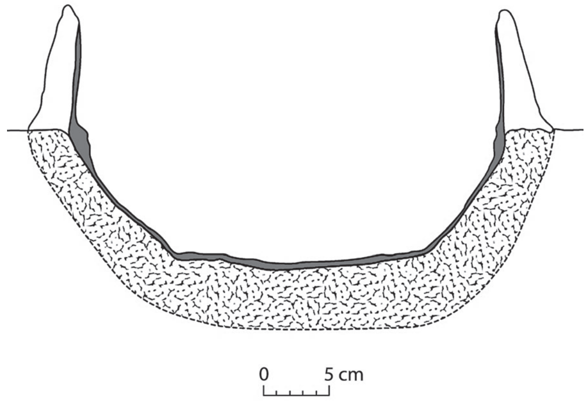

Fig. 3. A reconstruction of the "proto-furnace" likely used at Shiqmim and other Levantine sites in the early fourth millennium B.C.E. (adapted from Golden et al. 2001, fig. 8).

DISCUSSION

In this rebuttal, we have focused on debunking Amzallag's inaccurate comparison of crucible and furnace smelting and his arguments for the development of these technologies in different parts of the Old World. We have shown that crucible and furnace smelting methods are not in fact as different as the author suggests, and we have provided multiple examples of archaeological regions with strong evidence for the indigenous development of furnace technologies from earlier crucible smelting technologies. Contrary to Amzallag's vision of advanced furnace smelting originating in the southern Levant, we have demonstrated that the southern Levant was actually a rather conservative area as far as smelting is concerned. His proposal that skilled Levantine metalworkers traveled to all corners of the Old World, disseminating their superior knowledge, is entirely unsupported by archaeological or metallurgical data.

It is worth noting that Amzallag's argument is similar to that of V. Gordon Childe, as put forward particularly in the last editions of *Man Makes Himself* and *What Happened in History*.[72] The key difference, of course, is that Childe identified the Near East at large, rather than the southern Levant, as the region from which metallurgical innovation (and, indeed, "civilization") spread

[63] E.g., Higham 1996–1997; White 1997; Pigott and Ciarla 2007.

[64] Amzallag 2009, 497–98.

[65] Pigott and Ciarla 2007; White and Hamilton 2009.

[66] Amzallag 2009, 497.

[67] White 1988; White and Pigott 1996.

[68] White and Pigott 1996; Pryce 2009.

[69] Amzallag 2009, 499.

[70] The Non Nok Tha site report by Bayard remains unpublished, but Bayard (1980) is outdated. There is currently no definitive up-to-date statement on the site, and its stratigraphy and chronology are both known to be particularly complicated. See also White (2008), in support of an early second-millennium B.C.E. date for the appearance of bronze (cf. Higham and Higham 2009).

[71] Pigott et al. 1997; Pigott 1999a.

[72] Childe 1951, 1954.

to the rest of the Old World. Amzallag's "centrifugal process of expansion"[73] model for early metallurgy is essentially identical to Childe's arguments for "itinerant metal-smiths" as agents of both technological and social change. He updates Childe by (1) distinguishing between crucible smelting and furnace smelting and (2) proposing a second model for the transmission of metallurgy. This second model (his "centripetal expansion"—a curious oxymoron) involves colonies of metalworkers migrating directly to distant places to exploit new ore resources. While such directed population movements may have occurred in the past, evidence for ancient metalworkers doing so remains elusive.

Although Childe is rightly honored for his pioneering investigations of the Bronze Age social and political changes, his hypotheses about the hyperdiffusion of metallurgy, and its supposedly transformative effects on ancient societies, have long been discarded.[74] It is therefore disquieting to see Childe's technological determinism resurface in Amzallag's synthesis. Archaeological discoveries over the last 50 years have shown that the adoption of furnace metallurgy was not a primary cause of the social and political transformations that occurred during the Bronze Age. Metallurgy was but one of a number of technologies that inspired a growth in population and social complexity through increased trade, communication, and conflict. In Eurasia, these technologies include the spread of wheeled transport, the plow, the domestication of the horse, and the "secondary products revolution" (selective breeding of animals for milk and wool), to name but a few. Metallurgy was certainly part of the package, but to single out the adoption of metallurgy as the key innovation in the transformation of economic, social, and political life in Eurasia and beyond, as Amzallag does, betrays a basic lack of familiarity with recent archaeological literature.[75]

In conclusion, Amzallag presents a model of ancient metallurgical technology that integrates archaeological, metallurgical, and anthropological data. For this he should be commended, as such holistic interpretations are certainly the way forward for archaeometallurgy and other studies of ancient technologies. Unfortunately, his misunderstanding or misrepresentation of these data have led him to conclusions that may mislead the wider archaeological audience. Questions about the origins and spread of metallurgy in the Old World are far from answered, and we certainly need more debate and discussion about the data and the core issues involved. However, we must be careful to avoid sweeping historical narratives across vast amounts of time and space that ignore the highly variable regional and interregional developmental trajectories of early metal production and use.

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[73] Amzallag 2009, 510.
[74] See papers in Wailes 1996.
[75] E.g., Scarre 2005.

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